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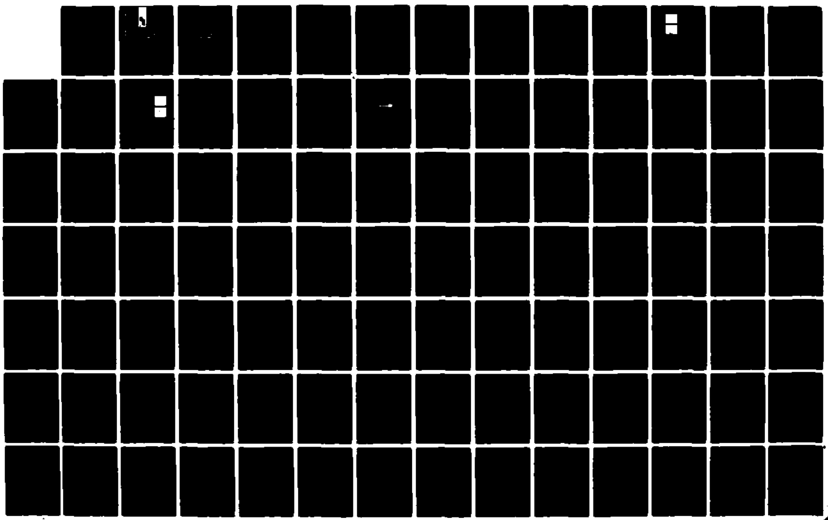

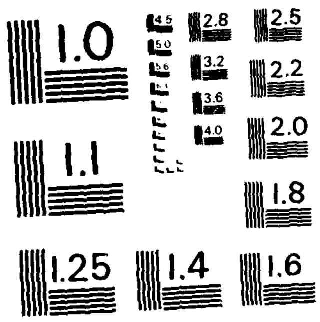
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Technical Memorandum

PARTICLE SIZING IN A FUEL-RICH RAMJET COMBUSTOR

R. TURNER
R. A. MURPHY

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PARTICLE SIZING IN A FUEL-RICH RAMJET COMBUSTOR

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A laser Doppler velocimeter (LDV) has been used to measure the size, concentration, and velocity of individual particles having diameters ranging from 3 to greater than 100 μm and having velocities of 600 to 1400 m/s in the fuel-rich exhaust of a ramjet combustor. The visibility of the LDV output was used to measure particle diameters ranging from 3 to under 30 μm and the mean scattered amplitude was used to measure particles ranging from 20 to over 100 μm. The attenuation of one LDV beam provided information on the total amount of material present. Measurements were made along the flow field of a combustor operating at 35 psia, an inlet temperature of 650 to 850 K, and fuel equivalence ratios (ER) of 1.6 and 2.6. Typically, at a point one-half inch from the nozzle and for an ER of 2.6, the average particle velocity is 800 m/s, the average particle size is 50 μm, and the particle density is 250 particles per cubic centimeter. The large particles appear to be unburnt fuel.

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ABSTRACT

A laser Doppler velocimeter (LDV) has been used to measure the size, concentration, and velocity of individual particles having diameters ranging from 3 to greater than 100 μm and having velocities of 600 to 1400 m/s in the fuel-rich exhaust of a ramjet combustor. The visibility of the LDV output was used to measure particle diameters ranging from 3 to under 30 μm and the mean scattered amplitude was used to measure particles ranging from 20 to over 100 μm. The attenuation of one LDV beam provided information on the total amount of material present. Measurements were made along the flow field of a combustor operating at 35 psia, an inlet temperature of 650 to 850 K, and fuel equivalence ratios (ER) of 1.6 and 2.6. Typically, at a point one-half inch from the nozzle and for an ER of 2.6, the average particle velocity is 800 m/s, the average particle size is 50 μm, and the particle density is 250 particles per cubic centimeter. The large particles appear to be unburnt fuel.

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1. INTRODUCTION

Nonintrusive diagnostic techniques are becoming more and more necessary in the study of combustion processes and high-speed flow fields. Nonintrusive diagnostics usually involve optical techniques and while those techniques can provide high data rates, good spatial resolution, and usually do not perturb the flow, their application presents problems unique to the particular optical technique and configuration used. The following report describes the development and preliminary tests of an instrument to measure the size and speed of single, large particles in the 3 to 100 μm range, in a supersonic flow. The number of particles (which consist of unburnt or partially burnt fuel droplets and possibly agglomerations of unburnt particles) in this size range and their evolution with time are of particular concern in the fuel-rich supersonic combustors now under development.

A variety of techniques has been developed that use light scattering to measure the size of particles such as the products of combustion or aerosols. In general, all of the available techniques make important assumptions that may include particle size distribution, particle shape, index of refraction, or particle size relative to the wavelength of the light source. Some techniques require an actual sampling of the flow for sizing measurements. Some methods use relative amplitude measurements while others use absolute measurements. Some measurements are for a single particle, others derive the results from a larger number of particles of various sizes. The method chosen depends largely on what parameters are important and on how well a system can be configured for the particular application. For our application it was decided that the information available from a standard laser Doppler velocimeter (LDV) be used to provide a simultaneous measurement of both the size and the speed of single particles in the flow. The LDV was originally developed to measure the velocity of particles in the flow and it is usually one of the first instruments considered for use in the present type of application. Only recently, however, has work been undertaken to use the information that the LDV provides to obtain particle size as well as the velocity. The high speeds and hostile environment encountered in a supersonic combustor present unique problems for this application.

2. LDV OPERATION

Figure 1 is a schematic diagram of the Thermo-Systems Inc. (TSI) LDV (configured for forward scattering) that is used for particular sizing. The output of a 5 mW, helium-neon, vertically polarized laser (with a wavelength of 0.6328 μm) is split into two beams of equal intensity that are focused to cross 250 mm from the lens at an angle of 2°. A particle at the intersection of the two beams will scatter light from each beam. The phase relationship between the two scattered signals as they appear at the light collector (in this case a photomultiplier (PMT)) depends on the particle's position relative to each beam, making both constructive and destructive interference possible. Even though the actual interference is measured at the detector, it is often convenient to think of the scattering volume as illuminated by a series of light and dark fringes produced by interference at the intersection of the two beams. The ellipsoidally shaped scattering volume (1.2×10^{-4} cm^3) is determined by the beam width of the focused laser, an aperture (250 μm diameter) located at the focal point in the collection optics, and the viewing angle. The minor axis of the ellipsoid, parallel to the flow, is 250 μm; the major axis, perpendicular to the flow, is 0.2 mm. Where high particle densities are anticipated, as they are in this application, it is desirable to minimize the scattering volume to permit a sufficiently high count rate of single particles. If two or more resolvable particles above a given size are present at the same time in the scattering volume, the instrument will not process them. The aperture in the collection optics limits the field of view at the center of the region to 16 vertical interference fringes that are spaced 17.6 μm apart. The fringe spacing (δ_f in μm) is given by

$$\delta_f = \frac{\lambda}{2\sin\gamma} , \tag{1}$$

where λ is the wavelength in μm and γ is one-half the angle between the two LDV beams. The plane of the fringes is parallel to the flow.

A particle moving through the scattering volume will produce a scattered light signal that is modulated at a frequency (f) proportional to δ_f and its component of velocity (v) perpendicular to the fringes. The modulation frequency is given by

$$f = \frac{v}{\delta_f} = 5.68 \times 10^{-2} v , \tag{2}$$

where f is in megahertz, v in meters per second, and

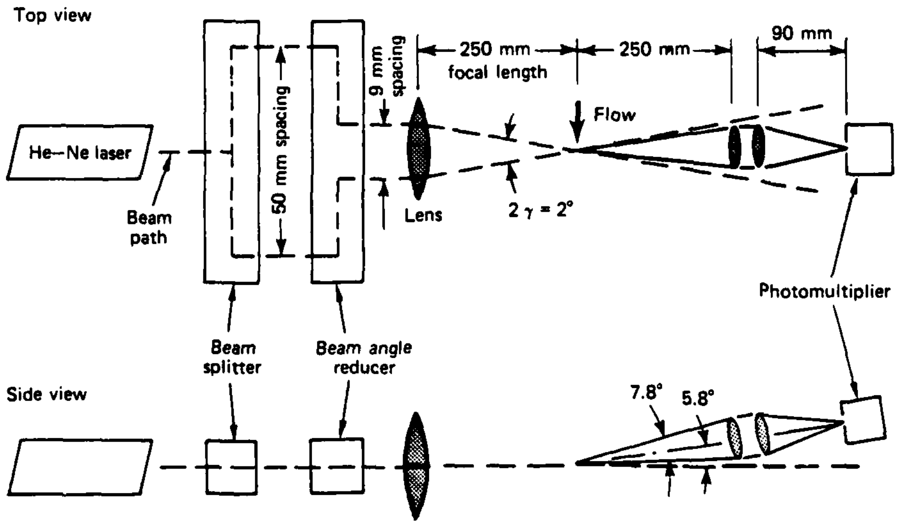

Figure 1 – LDV optical configuration.

δ_f is in micrometers. Particles moving at the speeds expected in actual combustors (600 to 1400 m/s) will produce scattered light pulses from 0.18 to 0.4 μs wide that are modulated at frequencies of 30 to 80 MHz. The actual choice of the LDV parameters involves a series of compromises. The beam width, crossing angle, aperture stop, and scattering angle determine the scattering volume and thus the number of particles that can be counted. In this case, the modulation frequency is as high as practical for the anticipated velocities. Reducing the crossing angle reduces the frequency at the expense of increasing the scattering volume.

The size of the particle producing the scattered light signal can be derived from the mean amplitude of the signal and the ratio of the depth of modulation of the scattered signal to the mean amplitude. The latter is often referred to as the visibility of the signal. Visibility is defined as $(I_{max} - I_{min})/(I_{max} + I_{min})$, where I_{max} and I_{min} are, respectively, the maximum and the minimum light intensity measured near the maximum signal of each scattered light pulse. Figure 2 shows two high-visibility signals measured under two different conditions. In Fig. 2a, obtained from fuel droplets in the test combustor, the visibility is 0.67; in Fig. 2b, obtained with dioctyl phthalate (DOP) aerosols, the visibility is 0.79. The two measurements of particle size are complimentary: the intensity of light scattered by small particles (<3 μm in the present case) is low, but the visibility is high (approx. 1); the intensity of light scattered by large particles (>30 μm) is large, but the visibility is low (<0.3). There are other important differences. The intensity is an absolute measurement and generally increases monotonically (for some optical configurations) with size. The visibility is a relative measurement and can be multivalued as the particle size increases. The dynamic range of the visibility in most cases is probably less than 10:1, whereas the dynamic range of intensity measurements can be much greater and can present a problem in this application. The intensity measurement has been the conventional method used to size particles[1,2]; the use of signal visibility for particle sizing is of fairly recent origin and the various aspects of its application and interpretation are considered in Refs. 3 through 16. Durst presents a recent comprehensive review of the use of the visibility technique[6]. The visibility measurement has been emphasized in this work because the range of sizes that can be measured can be controlled by the proper choice of optical components and angular position of the detector and because the particle sizes anticipated in actual combustors were in a range compatible with practical LDV configurations.

Equation 3 is an expression for the visibility (V), assuming that the particles are nonuniformly illuminated by the interference fringes in the scattering volume, has been derived by Farmer[3]. Because of the assumption involved, Eq. 3 is limited to near-zero scattering angles, small crossing angles, and large collection apertures. The visibility can be calculated for spherical particles from

$$V = \frac{2J_1(\pi D/\delta_f)}{\pi D/\delta_f}, \tag{3}$$

where J_1 is the first-order Bessell function, D is the particle diameter, and δ_f is the fringe spacing.

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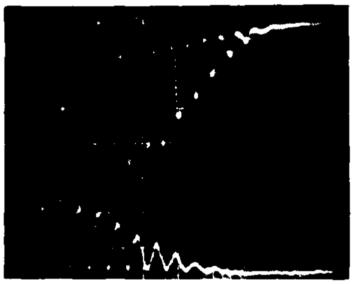

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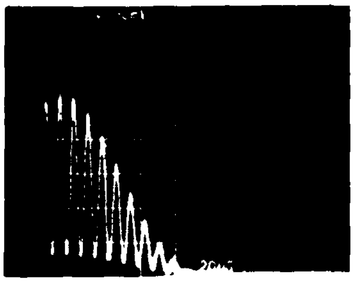

20 μs/div

Figure 2 – Typical high visibility signals obtained from the LDV in the forward scattering position. (a) This signal was obtained from a fuel-air mixture in the test combustor; the particle, having a diameter (derived from the visibility of the signal) of 15 μm is moving at 180 m/s. (b) The particle is a 12 μm DOP aerosol moving at 2.1 m/s.

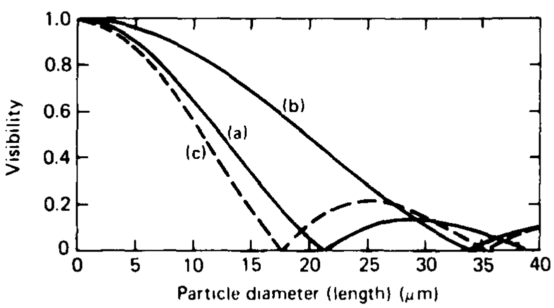

Figure 3 – Visibility plotted as a function of particle diameter (or length) using Farmer's approximation[3]. (a) Where particles are spherical and the beam-crossing angle is 2° (δ_f = 17.6 μm). (b) Where particles are spherical and the beam-crossing angle is 1.3° (δ_f = 27.9 μm). (c) Where particles are cylindrical and the beam-crossing angle is 2°.

In the present configuration, the visibility becomes

$$V = 2J_1(0.178D)/0.178D. \tag{4}$$

Figure 3 contains two plots of the visibility computed using Eq. 3 for the nominal crossing angle of 2° (curve *a*) and for a crossing angle of 1.3° (curve *b*), which is obtained by changing the focal length of the input lens from 250 to 400 mm. By this means the size range covered by the visibility technique can be extended to handle larger sized particles at the cost of reduced scattered light intensity. The visibility for cylindrically shaped particles is

$$V = \frac{\sin(\pi D/\delta_f)}{\pi D/\delta_f}, \tag{5}$$

where D in this case is one-half the length of the cylinder. The visibility for a cylinder is plotted as curve *c* for the same fringe spacing as curve *a*. Despite the smaller area that a cylinder can present compared to a sphere, the visibilities for the sphere and cylinder are not very different.

Equations 3 and 5, if used within their limitations, can give an indication of the particle sizes involved. However, the visibility and the scattered light intensity are both extremely sensitive to the F number of the collection optics and the location of the optics relative to the incident laser beams. In fact, the visibility and intensities as functions of the particle diameter can be tailored (as will be shown) by choosing the optical configuration to suit the expected experimental conditions. These limitations and the limitations of Eqs. 3 and 5 have been considered in detail by many authors, and in particular, the authors of Refs. 17 and 18. Because of these facts, it is extremely important that the instrument be calibrated accurately for the conditions under which it will be used and that the response function of the instrument can be predicted accurately. The response function is the PMT output signal produced by a given sized particle and is a function of the scattering angle, limiting aperture of the collection optics, and the focal length of the collection lens. A major portion of this work was devoted to the problems of calculating the response function and of calibrating the overall system.

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3. RESPONSE FUNCTION CALCULATION

Calculating the response function requires integrating the scattered light over the solid angle defined by the aperture and focal length of the collection optics. The intensity of the light scattered in any direction is a function of the scattering angle, the shape of the particle, its index of refraction, and the polarization of the incident light. The Mie theory[19,20] is the only exact theory available and it applies only to spherical particles. The intensity of the scattered signal, particularly for small particles with real indexes of refraction, can be very structured with deep fluctuations as the scattering angle changes. The Mie theory calculation becomes expensive for large sized particles because of the large number of terms that are required in the expansions used; the number of terms is approximately equal to alpha ($\alpha = \pi D/\lambda$), a conventional scale factor, and so is proportional to the particle diameter. There are simpler approximations that generally divide the problem into three components contributing to the scattered light: diffraction, refraction, and reflection. The contribution of each component depends on the particle size, index of refraction, and scattering angle; some of the approaches in this direction are listed in Refs. 21 through 24. Farmer[4,5], in particular, and Bachalo[25] have tried to extend the visibility approach to angles other than forward scattering, but all these approximations, because of their limitations, present uncertainties in applications of this type.

Because two beams are used in the LDV, the vector components $E_\perp$ and $E_\parallel$) of the scattered light for each beam must be calculated and then transformed into a common scattering plane where the components can be added vectorially. The scattering geometry used to calculate the visibility and the mean intensity are shown in Fig. 4. The scatterer is located at the origin (0) and the two laser beams crossing at an angle of 2γ in the Y-0-Z plane are indicated by the propagation vectors k_1 and k_2. The laser is vertically polarized with its electric field vector (E_i) parallel to 0-X. The three scattering planes c nsidered are indicated as 0-1-3 for the left beam, l ng toward the laser, and 0-2-4 for the right beam d 0-Z-5 for the combined scattering plane.

The electric vector co nents that are parallel to a scattering plane are d ted by 2 and those perpendicular to the scatte e by 1 (this designation is a fairly standa ention). The electric field components are indicated as follows: $E(2)$ and $E(1)$, the parallel and perpendicular components in the combined scattering plane; $E2(1)$ and $E2(2)$, the parallel components from beams 1 and 2, respectively, in their respective planes; and $E1(1)$ and $E1(2)$ are the corresponding perpendicular components. The parallel and perpendicular components of the scattered field are added vectorially in the combined plane to give the resulting perpendicular and parallel components. The electric field vectors are used, in turn, to compute the total collected power. The maximum and minimum collected intensities from which the visibility and the mean scattered intensity are calculated are obtained first by adding the components from beams 1 and 2 in phase to give the maximum signal and then subtracting them (the phase of beam 2 is shifted 180°) to give the minimum signal.

The integration is indicated by

$$P/2I_0 = \int_0^{\pi/2} d\phi \int_0^{\theta(u)} F(\theta,\phi)\sin\theta \, d\theta \,, \tag{6}$$

where P is the collected power and I_0 is the total incident laser power. A more standard form is

$$P/2I_0 = \int_0^{\pi/2} d\phi \int_0^{\theta(u)} [I_1(\theta)\sin^2\phi + I_2(\theta)\cos^2\phi]\sin\theta \, d\theta \,. \tag{7}$$

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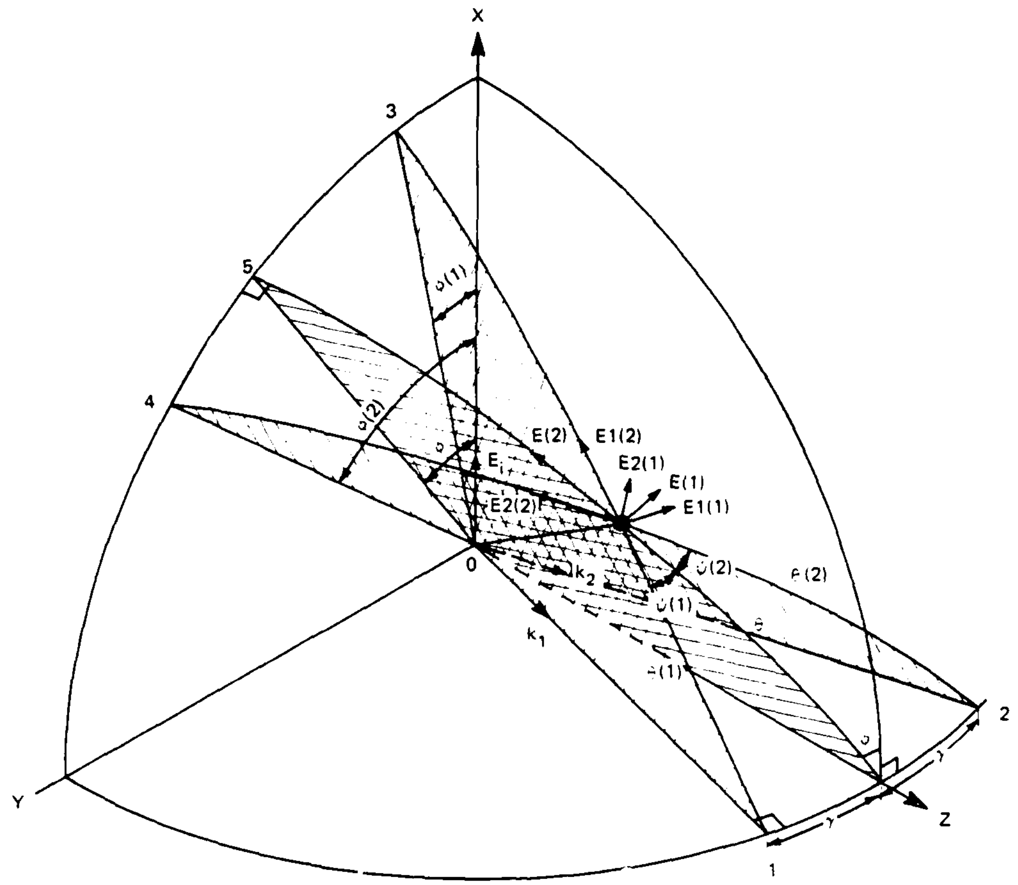

Figure 4 – Geometrical configuration of the LDV beams and their scattered vector components.

The integration is over a circular aperture centered in the X-0-Z plane and above the Y-0-Z plane (the actual program does not have this last restriction), where the upper limit is calculated by

$$\theta(ul) = \cos^{-1}\left[\cos\left(\frac{a}{z}\right) - \frac{\cos\theta\cos(\theta_{min} + a/z)}{\sin\theta\sin(\theta_{min} + a/z)}\right], \tag{8}$$

where a is the aperture radius, z is the focal length, and θ_{min} is the minimum aperture angle. $I_1(\theta)$ and $I_2(\theta)$ are the perpendicular and parallel scattered intensities in the combined scattering plane. The intensities I_1 and I_2 are related to the scattered field intensities:

$$I_1(\theta) = |S_1(\theta)|^2$$
$$I_2(\theta) = |S_2(\theta)|^2 \tag{9}$$

The simplest approximation applicable to large particles at very small forward scattering angles is the diffraction approximation[9,20]. In this case,

$$S_1(\theta) = S_2(\theta) = \frac{k^2 d^2}{4}\,\frac{J_1(x)}{x},$$

where

$$x = \frac{kd\sin\theta}{2} \tag{10}$$

The diffraction approximation does not include the contributions to the scattered light that are caused by the optical properties of the particle (a hole or a similarly shaped opaque mask will produce the same diffraction pattern). Appendix A lists the Fortran program used to calculate the visibility and collected power from a spherical particle, using the diffraction approximation. The calculated visibility and intensity for a scattering angle of 5.8° (which is the normal forward scattering angle used in calibration and tests) are plotted in Figs. 5 and 6. The differences between the visibility calculated in this fashion (curve 5*b*) and the visibility derived from Farmer's equation (curve 5*a*) can be clearly seen. With the aperture and the scattering angle used, a large fraction of the scattered light (particularly for the larger sized particles) is not collected.

It is clear from the above results that a more exact calculation is required even at these small scattering angles. Several programs have been developed to calculate the required Mie coefficients, S_1 and S_2.

Appendix B lists the Fortran program that incorporates a Mie program developed by Grehan and Gouesbet[26,27]. This version has the advantage that it can handle indexes of refraction having large imaginary components. The visibilities and mean scattered intensities calculated with the Fortran program in Appendix B for DOP and a soot-hydrocarbon mixture for selected diameters are shown in Figs. 5 and 6. DOP has an index of refraction $n = 1.49 - i0.00$ and was chosen because it was used to calibrate the instrument. The soot-hydrocarbon mixture, which has an index of refraction $n = 1.67 - i0.33$, was chosen because it is assumed to be representative of the partially burned combustion products present in the flame. The results indicate that the diffraction approximation is reasonable for sizing partially burnt fuel; the imaginary component of the index reduces the effects of the optical properties of the particle. However, the effect of the index of refraction must be considered in the calibration, the choice of scattering angle, and the sizing of fuel droplets in both the case of visibility and the mean scattered intensity. A very recent and related calculation for a variety of

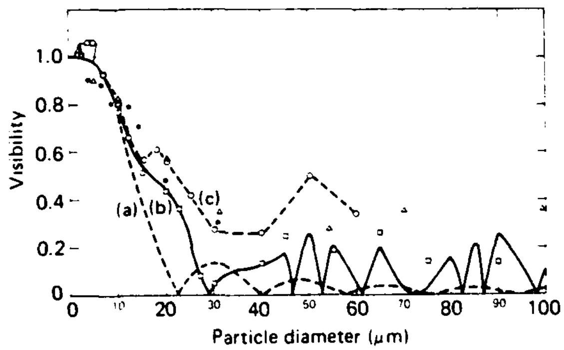

Figure 5 – Calculated and measured visibility plotted as a function of particle diameter. The plotted data, except for (a), are for a detector with a 250 mm focal length, with a 34 mm aperture, a scattering angle of 5.8°, and a beam-crossing angle of 2°. Derivation of the curves is as follows: (a) The calculated visibility using Farmer's approximations; (b) The calculated visibility using the diffraction approximations (Appendix A); and (c) The calculated visibility using the Mie Theory (Appendix B) for DOP. O Mie calculation for DOP, $n = 1.49 - i0.00$; □ Mie calculation for soot/hydrocarbon, $n = 1.67 - i0.33$; Δ measured values (relative) for polystyrene spheres, $n = 1.59 - i0.00$; and * measured values (relative) to DOP aerosols.

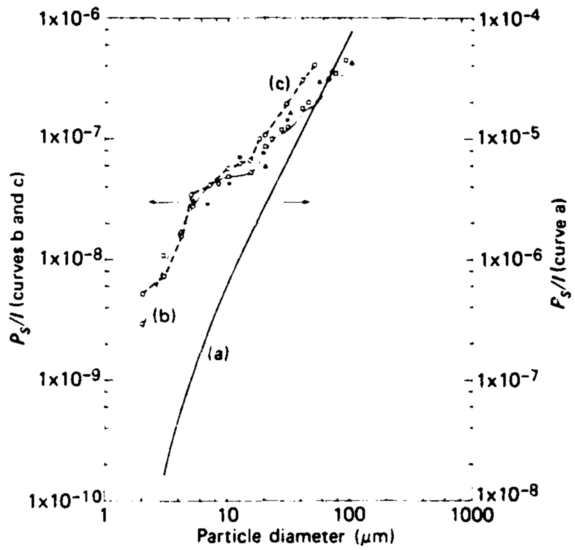

Figure 6 – Calculated and measured values of the mean scattered intensity as a function of particle size. The plotted data, except for (a), are for a detector with a 250 mm focal length lens and a 34 mm aperture located 5.8° above the plane of the LDV beams. The beam-crossing angle is 2° and the fringe spacing is 17.6 μm. Derivation of the curves is as follows: (a) Intensity was calculated using the diffraction approximation (Appendix A) with the detector centered between the beams in the plane of the LDV beams. (b) Intensity was calculated using the diffraction approximation. (c) Intensity was calculated using the Mie Theory (Appendix B) for DOP. O Mie calculation for DOP, $n = 1.49 - i0.00$; □ Mie calculation for soot/hydrocarbon, $n = 1.67 - i0.33$; Δ measured values (relative) for polystyrene spheres, $n = 1.59 - i0.00$; and * measured values (relative) to DOP aerosols.

[26] G. Grehan and G. Gouesbet, "Mie Theory Calculation: New Progress, with Emphasis on Particle Sizing," *Appl. Opt.*, **18**, 3489 (1979).

[27] G. Grehan and G. Gouesbet, "SUPERMIDI" Report TTI. 79 20 03, Laboratory de Thermodynamique, Universite de Rouen 76130 Mont-Saint-Aignan, France.

aperture conditions is reported in Ref. [illegible], the possibilities of tailoring the system for a particular visibility vs. particle diameter is clearly indicated.

The more exact program has been used to calculate visibility and intensity at 90 and 160°, which are two regions where visibility measurements in particular would be desirable and where any approximations are suspect. Figure 7 is a plot of the visibility for scattering angles of 90 and 160° using Farmer's approximate formulas[5]. At these angles the size range that can be measured can be tailored, within the experimental constraints, by choosing the F number of the collection optics. For the case of 90° side scattering, the visibility computed from Farmer's formula for a 48 μm DOP particle is 0.83 and that calculated with the exact theory is 0.7. These agree reasonably well with the measured visibility of 0.88. For the case of 160° backscattering (the maximum backscattering angle less than 180° that could be accommodated in the present setup) the results are not as good. This time the visibility from Farmer's formula for a 48 μm DOP particle is 0.96, the calculated value with the Mie theory is 0.32, and the measured value is 0.7. The limitations on the measured values are discussed later.

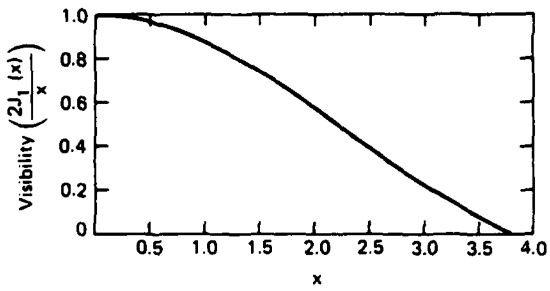

Figure 7 – Visibility versus scale factor (x) for side and backscattering conditions using Farmer's approximation[5]. The focal length is 120 mm, the aperture is 34 mm and F is 3.5. For 90° scattering, $x = 2\pi(D/\delta)/4F$, where F is the F number of the collection optics and $D = 29.4x$. For 160° scattering, $x = \pi(D/\delta)/4F(1 + 1/2 \tan^2 \beta)$, where β is the scattering angle and $D = 84.0x$.

[28] C. R. Negus and L. E. Drain, "Mie Calculations of the Scattered Light from a Spherical Particle Traversing a Fringe Pattern Produced by Two Intersecting Laser Beams," *J. Phys. D: Appl. Phys.*, **15**, 375 (1982).

4. PSI CALIBRATION

Three methods have been used to calibrate the PSI over velocities ranging from 3 to 400 m/s: (a) polystyrene spheres 5 to 100 μm in diameter, (b) DOP aerosols 1 to 50 μm in diameter, and (c) aluminum oxide particles approximately 5 to 25 μm in diameter. Unfortunately no facilities were available for calibrating at the speeds encountered in the actual combustor; therefore, for this calibration a simulated signal (described in detail in Appendix C) was inserted at the PMT output. The simulated signal could be adjusted to vary the pulse width, the amplitude, the fringe frequency, and the number of modulation fringes.

The polystyrene spheres (index of refraction, $n = 1.59 - i0.00$) were electrostatically attached to a 250 μm thick glass microscope slide, which in turn was mounted on a rotating wheel. With this technique, the PSI signal can be identified with a particle whose size, shape, and index of refraction as well as position in the scattering volume are known. Speeds of up to 20 m/s were used. Figure 8*a* shows an image of a 31 μm particle centered in the LDV scattering volume (the actual fringe spacing can be obtained from this photograph.). Figure 8*b* shows the PMT output signal when the particle is moved through the scattering volume at 20 m/s. The results of these measurements are plotted on Figs. 5 and 6 and agree well with the Mie calculations.

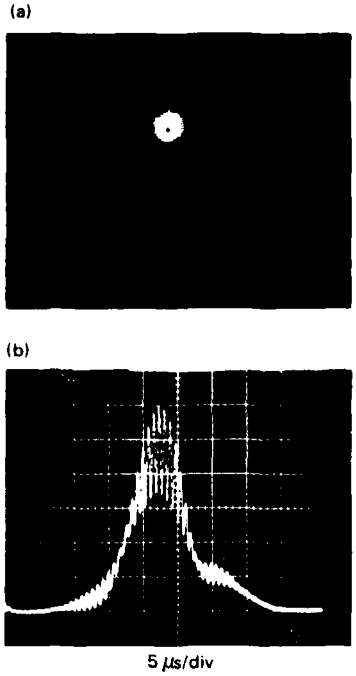

Figure 8 – (a) Image of 31 μm polystyrene sphere in the 17.6 μm fringe system; (b) PMT output produced by the 31 μm sphere mounted on a rotating glass slide.

A Berglund-Liu aerosol generator (Thermal Systems, Inc., Model 3050) operated in both the upright and the inverted positions (with 20 and 50 μm orifices and with DOP concentrations in alcohol of up to 10%) was used to provide aerosols from 4 to 48 μm in diameter. It was difficult, however, to get a reliable supply of the larger sized aerosols from the generator. The sizes of the aerosols produced were routinely measured with a microscope. During these measurements, an impact spreading factor of 3, as indicated in Ref. 29, was independently confirmed. The Berglund-Liu aerosol generator was used because of the uncertainties associated with the spheres mounted on substrates and to provide a larger number of particles moving at higher speeds than would be available otherwise. The data obtained with the DOP aerosols moving at 3 m/s (the typical speed of the aerosols leaving the generator) are plotted on Figs. 5 and 6. These data show agreement with the results obtained with polystyrene, but again indicate the sensitivity of the results to the index of refraction. The output of the aerosol generator was injected into a small supersonic air jet, which gave particle speeds of up to 400 m/s. The sizing measurements with particles up to 8 μm in diameter moving at 300 m/s agreed with the results obtained for the same size particles moving at 3 m/s. However, the results obtained when the larger particles were used did not agree with the results for the large sized particles at low speed. The PSI measurements and limited microscopic measurements indicated that the large sized particles were probably breaking up in the high-speed constricted flow.

[29] B. Y. H. Liu, D. Y. H. Pui, and Xian-Qing Wang, "Drop Size of Liquid Aerosols," *Atmos. Environ.*, **16**, 563 (1982).

The results with aluminum oxide particles were consistent with the results for DOP and polystyrene, but were much more erratic because the distribution of particles sizes was large and the particle shapes were very irregular.

The calibration at scattering angles of 90 and 160° was limited to a single size (48 μm DOP) because of time restrictions and the lack of suitable larger particles. The 90° visibility results agree well, as discussed before, but the 160° results did not agree as well. There were additional problems because of the reduced scattered signal even for the larger particles and at 90° alignment problems became significant. Additional calibration points are required before these scattering angles can be used with any confidence.

5. PARTICLE SIZING INSTRUMENTATION

Figure 9 is a detailed block diagram of the particle sizing instrumentation used to select suitable individual particles and to derive the size and speed information from the selected particles. The collected light is detected with an RCA type 4526 PMT, which is normally operated at −900 V (−1100 V was used for the 90 and 160° scattering angles). The thresholds and saturation limits within the system required that the signal at this point be in the range of 15 to 700 mV. The PMT output is amplified ten times and then filtered by a low-pass filter (with a cutoff frequency of 5 MHz) to remove the high-frequency modulation and to provide the mean value of the scattered intensity $(I_{max} + I_{min})/2$. The PMT output is also filtered by a band-pass filter (having a band pass from 20 to 100 MHz) to obtain the high-frequency modulation. The resulting AC signal is peak detected with a HP 8470B crystal detector with a matching 50 Ω load to provide $(I_{max} - I_{min})/2$. The detected pulse is run through a fast source follower (National Semiconductor LH0063C)), inverted to provide a positive-going pulse, and amplified ten times. If a negative-going gate pulse (indicating no pulse pile-up) is present at this point, the two pulses are stretched to the length of the gate pulse (0.6 μs) and fed to the peak-sense-and-hold module (Optical Electronics Inc., Model 5030A). This module receives both a gate pulse and a reset pulse. During the time that both are present, the circuit acquires the most positive value of the input signal. Thereafter, the circuit is insensitive to changes in the input signal and holds its peak value for the duration of the reset pulse. The input pulse, if it is an acceptable pulse, is gated on through a linear gated amplifier.

The amplified output of the bandpass filter is also sent to two fast discriminators (LeCroy Research Systems, LRS-161, 100 MHz) that provide narrow (5 ns), fixed-amplitude pulses when their input signal exceeds a threshold of 100 mV. Discriminator 1 provides a single pulse for each scattered light pulse whose AC amplitude exceeds the threshold. This pulse is used to trigger a gate-and-reset generator. The gate-and-reset generator is the source of the synchronized pulses that activate the system for signal processing, reset it when the processing is complete, and ensure that only a single PMT pulse is selected for processing. It produces a gating pulse of 0.6 μs and a reset pulse of 20 μs. The 0.6 μs pulse minimizes the chances that the system will act on two closely spaced pulses from the PMT. The 20 μs pulse controls the hold time of the peak-sense-and-hold circuits and resets the system for the next PMT pulse to be examined. The generator cannot be triggered until the end of the reset pulse. The 20 μs pulse length was required by the tape recorder used in the tests; it can be easily modified to accommodate the requirements

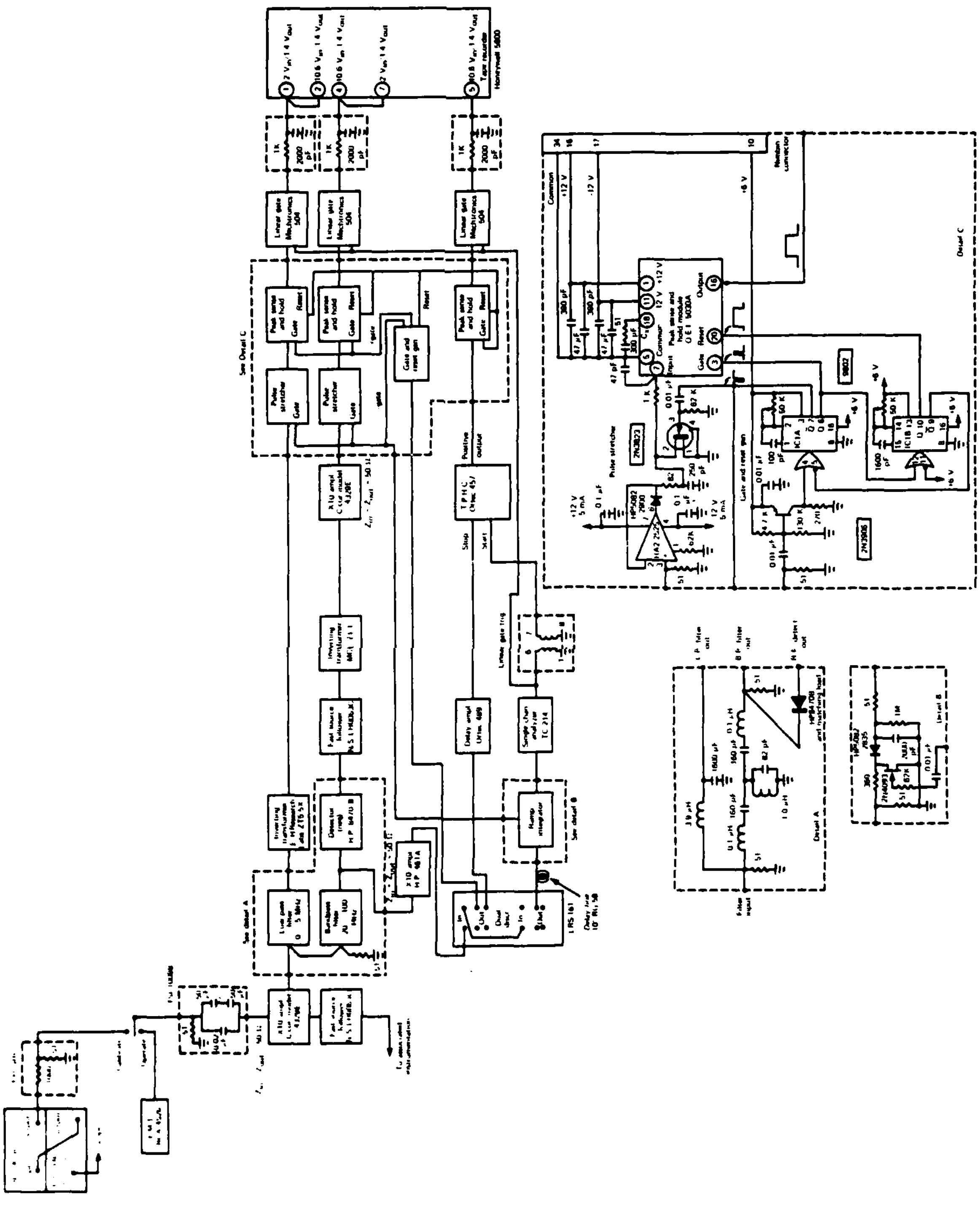

Figure 9 – Schematic diagram of particle sizing instrumentation (PSI).

of an A/D converter or other device. In principle, the reset time sets the system data rate at 50,000 particles/second, which is actually further reduced by the *additional restriction* (described below) that the particle pass through the center of the scattering volume.

The output of discriminator 2 is a train of narrow pulses equal to the number of fringes crossed by the particle or particles and is used as a second means of determining valid signals. A valid signal contains exactly 16 cycles of modulation on the signal produced by a particle crossing the 16 fringes in the center of the LDV scattering volume. Particles that are off center or are followed closely by a second particle will produce either more or less cycles of modulation during the 0.6 μs gating period. The discriminator produces an output pulse for each cycle of modulation. All pulses have the same amplitude and their width is adjusted so that 16 pulses in the range of 30 to 80 MHz produce outputs of nearly equal amplitude from the gated ramp generator. The single channel analyzer (SCA) amplifies and shapes the ramp voltage so that only a signal with 16 fringes will fall in the SCA selection window and produce an output pulse. It is this pulse that triggers the linear gated amplifier and allows the processed signal to be recorded. This restriction also ensures fairly uniform illumination for particles that are not too large (< 100 to 150 μm).

The SCA pulse, which is related to the time to the 16th cycle of modulation, also becomes a start trigger for the time-to-pulse-height converter (TPHC). The TPHC produces a 0 to 10 V output pulse having an amplitude that depends on the time difference between the start and stop pulses. The output of discriminator 1, which occurs at the start of the modulation, is delayed more than the actual length of the scattered pulse so that it can be used as a stop pulse. With this technique, the TPHC is activated only when valid signals are present; the faster particles produce signals of greater amplitude than the slower particles. The TPHC signal is also stretched and held for future recording.

6. PARTICLE COUNT

In addition to the measurements of scattered intensity and particle visibility, the flux of particles greater than about 3 μm in diameter is counted. The minimum sized particle counted is determined by the individual pulses that exceed the threshold of discriminator 1 and so is a function of laser power, PMT voltage, and particle density. The maximum count before pulse pile-up becomes a problem is about 10^6. The average density of particles in the flow is computed from

$$n = \frac{N}{Av} \approx \frac{N}{440} \text{ (for high velocity flow),} \qquad (11)$$

where n is the particle density (particles/cm^3), N is the number of counts/second, v is the velocity in cm/s, and A is the LDA scattering area cross section (6.3×10^{-3} cm^2).

The output of discriminator 1 is used to trigger a photon counter (an Ortec 9315 digital counter used with an Ortec 9325 analog counter), allowing the count for 0.1 second to be recorded. For the tests described here, the count rate and the transmitted laser power were recorded together on a strip-chart recorder. An example of the recorded data is shown in Fig. 10. The section shown gives an idea of the large fluctuations in count rate that are sometimes observed – a point that is discussed in more detail later.

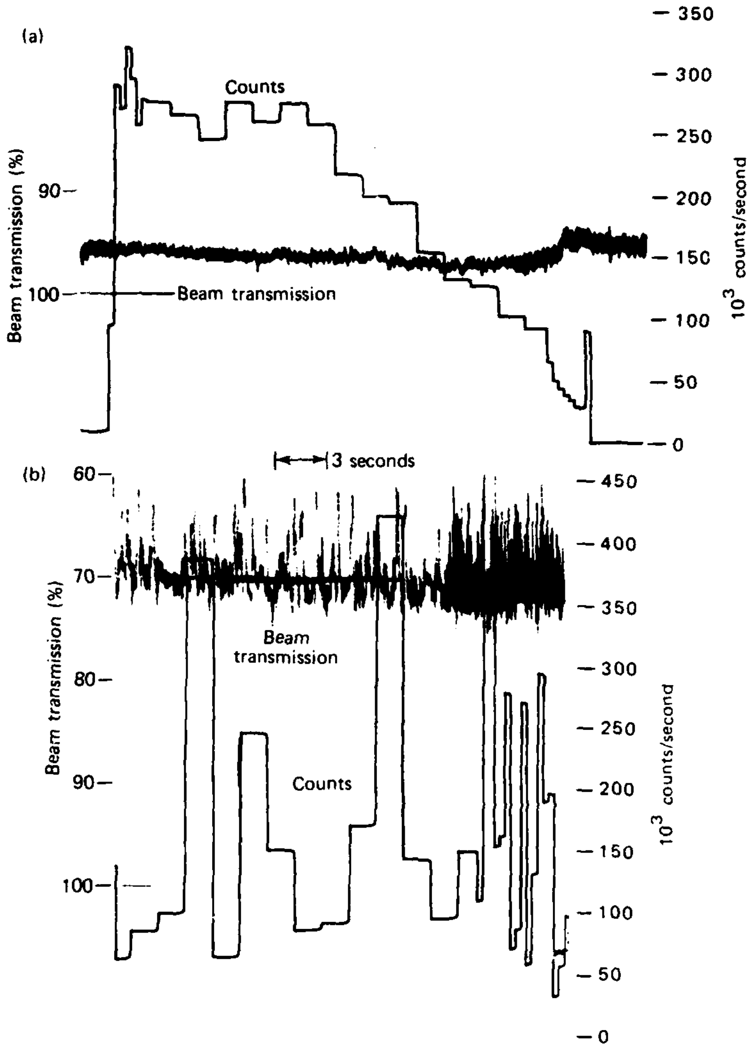

Figure 10 – A representative sample of the particle-count measurement and the beam transmission measurement. The LDV was positioned 5.06 in. from the nozzle and the ER was 2.5. (a) Fuel/air mixture only; (b) Burning mixture.

7. BEAM TRANSMISSION

The integrated effects of particle density, size, and scattering path length attenuate the LDV laser beams. The attenuation of one of the laser beams was measured during the tests to indicate the total amount of material in the flow and to confirm qualitatively the particle sizing results determined by the visibility and intensity measurement.

The transmission ratio, I/I_0, where I is the measured intensity with particles present and I_0 is the intensity when no particles are present, is the integrated result of particle density n, extinction efficiency Q_{ext}, particle cross section s, and the path length l, i.e.,

$$I/I_0 = exp \int_0^l - n Q_{ext} \, s \, dl . \qquad (12)$$

The Q_{ext} is very close to 2 for most of the particles of interest, and it probably averages more nearly 1 for the great number of smaller particles that contribute to the beam attenuation. Since this measurement is an average along the beam path through the flame, average values have been assumed and a $Q_{ext} = 2$ has been assumed for all results quoted. The path length was derived from photographs of the scattered laser beam.

After the LDV beam passed through the combustion zone it was chopped and deflected to a silicon *pin* diode (UDT-10DP) detector. The detector was covered with an adjustable iris and a 0.6328 μm band-pass filter. The output of the detector was demodulated with a phase-locked detector and recorded together with the particle-counter output. The iris was set to its minimum opening of 2 mm for most measurements, ensuring that for the distance to the detector (600 mm) from the scatterers, the scattering from particles less than about 100 μm would not be detected. As particle diameters become larger, more of the diffracted energy will be measured, with the result that their scattered light contribution would not be included in the attenuation measurement. Ideally, it would be desireable to monitor the instantaneous laser power and use it to normalize the transmitted signal, but time did not permit. Transmission measurements before and after the combustor tests indicated that there was no significant variation of the laser output during the runs.

8. COMBUSTOR MEASUREMENTS

A series of tests was made on the fuel-rich ramjet combustor[30], in Test Cell 5 at the APL Propulsion Research Laboratory, on July 13, 14, and 15, 1982, to evaluate the suitability of the instrument for the intended application. All the data involving particle sizing were recorded on magnetic tape or a strip chart in the test cell and were synchronized with the combustor performance data recorded outside the test cell. A limited amount of the data was reduced manually to determine how the instrument and the combustor were performing. Measurements were made with the LDV scattering volume located on the centerline of the exhaust plume at selected distances from 0.25 to 9 in. from the combustor exit nozzle. Most of the measurements were made with the LDV collection optics positioned at an elevation angle (with respect to the plane of the LDV beams) of 5.8° – forward scattering. Limited measurements were also made at scattering angles of 90 to 160° to explore the effect of scattering angle on the visibility. The combustor was operated at a nominal pressure of 35 psia, an air inlet temperature of 650 to 870 K, and at fuel ER's of 2.6 and 1.6.

A typical run lasted 30 to 60 seconds during which particle sizing and velocity information were obtained on about 1000 particles. For the purposes of this evaluation only 50 to 55 points were reduced at each LDV position. The majority of the particles measured were larger than expected, and the size determinations were based mainly on the intensity of the scattered signal. The intensity signal was calibrated on the basis of those cases where good visibility information and intensity information were available from the same particle. The laboratory-derived calibration curve was used for the larger sized particles.

Table 1 lists the average values and the standard deviations of the particle size and velocity at selected distances from the nozzle for an ER of 2.6. Figure 11 contains plots of the average diameter, the average particle speed, and the negative log of the transmission ratio. The speed of the particles increases in the first two inches from the nozzle from 690 to 790 m/s, which is the region of the accelerating flow field. The particle speed then decreases monotonically with increasing distance from the nozzle to the minimum of 528 m/s that could be measured with the instrument during these tests. The particle diameter decreases with distance from the nozzle for the first five inches and then increases at greater distances downstream. The negative of the log of the transmission ratio increases linearly with distance for the first five inches and then remains constant as the distance increases. In general, the fluctuations of the transmitted signal increase with distance from the nozzle. Wide variations in the particle count were observed, particularly at the greater distances from the nozzle, but averaged around 100,000 counts/second at all positions.

Table 1 – Average values and the standard deviation of the particle size and velocity at selected distances from the nozzle (ER = 2.6).

Position from Nozzle Exit (cm)	*Velocity*		*Diameter*	
	Ave (m/s)	*σ (m/s)*	*Ave (μm)*	*σ (μm)*
0.64	690	86	53.7	40.1
1.27	703	99	67.0	38.1
2.54	739	103	61.7	37.9
5.08	780	114	62.0	34.2
7.6	716	131	44.2	30.5
10.2	677	100	53.0	33.4
12.7	<554	57	43.0	26.9
15.2	<528	—	50.4	31.7
17.8	<528	—	51.1	30.0
20.3	<528	—	74.7	38.1
22.9	<528	—	80.0	31.0

Table 2 and Fig. 12 contain the same type of information and plots as Table 1 and Fig. 11 but for an ER of 1.6. The results are similar. The particle size again decreases and then increases with distance from the nozzle. The maximum velocity is slightly higher and does not drop off as rapidly. The transmission is about one-half that measured for an ER of 2.6. The particle count rate is approximately constant at 40,000 counts/second. These results are consistent with those derived from the higher ER value and are in the direction expected at the lower ER value.

[30] R. E. Lee, R. Turner, and F. S. Billig, "Particulate Measurements in the APL Fuel-Rich Ramjet-Combustor Supersonic Exhaust Flow," Proc. 1980 Fall Meeting of Western States Section The Combustion Institute, 20-21 Oct 1980.

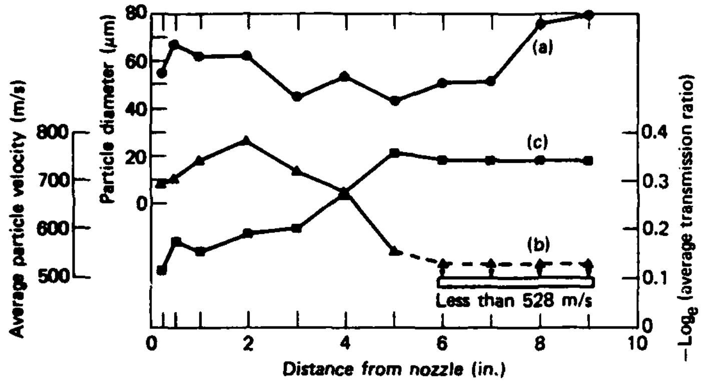

Figure 11 – The average values of the measured (a) diameter, (b) speed, and (c) negative log of the transmission ratio (turbidity), each plotted as a function of distance from the exhaust nozzle for an ER of 2.6.

Table 2 – Average values and the standard deviation of the particle size and velocity at selected distances from the nozzle (ER = 1.6).

Position from Nozzle Exit (cm)	*Velocity*		*Diameter*	
	Ave (m/s)	*σ (m/s)*	*Ave (μm)*	*σ (μm)*
0.64	619	98	49.5	25.9
1.27	715	159	53.1	31.0
2.54	779	157	58.9	36.1
5.08	819	150	62.1	38.5
7.6	747	164	57.9	37.6
10.2	741	156	57.0	35.7
12.7	694	170	39.1	25.4
15.2	43% <528	—	44.6	29.2
17.8	69% <528	—	54.3	34.3
20.3	74% <528	—	65.5	39.2
22.9	67% <528	—	69.7	36.7

Measurements were also made at both ER's for nonburning fuel/air mixtures. No detailed particle-size data were obtained because the particle speed (160 m/s) was below the minimum speed of the instrument. The data were obtained by photographing the PMT signals produced by individual particles. For the nonburning fuel/air mixture (ER = 2.4), the transmission ratio (I/I_0) was 0.96; the particle count, 275,000 counts/second; the average speed, 160 m/s; and the estimated path length, 2 cm at the measurement position. For these conditions, the calculated particle density is 2750 particles/cm^3. The average particle diameter is 22 μm (assuming that the particles counted are the only particles present, that there are no small particles, that the scattering path length is the same as that measured photographically in the burning case, and that Q_{ext} = 2). The particle diameter derived from individual visibility measurements is 15 to 20 μm. The agreement in size, as derived by the two methods, is good despite the fact that limited data were available; this agreement indicates that it is reasonable to assume that most of the particles (in this case) were large. The mass flow calculated from these results is more than 12% of the actual mass flow of the input fuel to the combustor. Similar calculations based on beam transmission measurements with a burning mixture (ER = 2.6) at a point 2 in. away from the nozzle give a particle density of 246 particles/cm^3 and an average particle size of 155 μm. The diameter calculated from the transmission measurement is much greater than the 50 μm diameter measured by the particle-sizing apparatus, indicating that a large fraction of the particle mass is carried by particles smaller than the 3 μm sized particles that can be counted directly. It is expected that a large fraction of the burning or burnt particles will be small.

The measured decrease in particle size as distance from the nozzle increases appears to be real. However, because the small particles slow down faster than the large ones, and considering the shock structure involved and the transient nature of the flow, the density of small particles in the LDV measuring volume can be greater than the density of large particles. In this case, the size distribution will be skewed to the smaller particles, as was observed. On the other hand, if the measured particles are fuel droplets, it would be expected that some evaporation would take

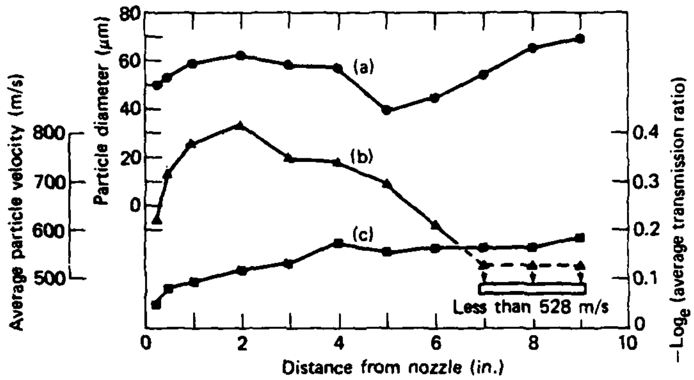

Figure 12 – The average values of the measured (a) diameter, (b) speed, and (c) negative log of the transmission ratios (turbidity), each plotted as a function of distance from the exhaust nozzle for an ER of 1.6.

place in the high temperature air as the distance downstream increases; hence smaller average particle diameter. The increase in particle diameter at distances greater than 5 in. from the nozzle is almost certainly an artifact. The slower small particles drop below the minimum speed for which their diameters can be measured before the faster large particles do, with the result that more large particles than small particles are measured.

The results obtained from the measurements at scattering angles of 90 and 160° were limited because of the poor signal-to-noise ratio and the difficulty with LDV alignment, particularly at 90°. It was necessary in both cases either to remove the field-limiting aperture or to increase its diameter substantially, resulting in a particle count rate that was greater than could be handled by the PSI. A very limited sample of data at 160° for the fuel/air mixture gave a visibility measurement of 0.33 compared to a calculated value of 0.32 for a 48 μm particle. Although these results may be just coincidental, they do show some promise.

9. CONCLUSIONS

Both laboratory measurements and measurements made under actual test conditions have shown that the output of a standard LDV can be used to provide simultaneous measurement of the diameter and velocity of individual particles in a supersonic flow. Procedures and computer programs have been developed to calibrate the instrument and to calculate its response function for a variety of operating conditions. This last requirement is quite important, particularly if other than small forward scattering angles are used.

The instrument used in the actual combustor test performed well. The size of the particles, however, was larger than was expected and the particles also moved more slowly than was expected. A much lower speed-gate limit would have been desirable for these tests. The larger-than-expected particle sizes (which were most likely unburnt fuel) meant that it was necessary to place greater reliance on the intensity measurement for particle sizing. The limited dynamic range of the visibility technique together with the multivalued condition requires a simultaneous intensity measurement in any actual combustor measurement.

There are still many points that must be considered before any measurement of this type can be accepted with confidence. The flame under study has a complicated shock structure for most of the region of measurement and contains a large number of small particles. The possibility that the coherence of the two LDV beams can be affected by the conditions in the flame must be considered. If the coherence is affected, there would be a reduction of the measured visibility and resultant distortion of the size measurement, but based on other reported LDV velocity measurements this does not appear to be a serious problem. However, any future measurement should include actual seeding of the flame with noncombustible particles of known sizes to establish that this is really the case and to provide a calibration of the instrument under actual operating conditions. The beam attenuation measurements indicated that multiple scattering was taking place, particularly downstream for the higher ER's. The attenuation measurement proved to be a useful complement to the PSI approach and it is thought to be appropriate that advantage be taken of such similar simple diagnostics in future measurements. This measurement is very sensitive to refractive effects in the flame because of the small aperture required to extend the range of sizes of particles included in the measurement. Any future measurements should be comprehensive enough to establish whether refractive effects are playing any part. Data reduction should be automated; the present instrument can easily be modified so that on-line processing of much larger amounts of data can be handled by a minicomputer. The exigencies of the situation forced the use of an antiquated data-handling technology.

The results raise questions that could use help from other directions. Some of these questions include (a) "are the sizes measured consistent with the fuel injectors and combustion conditions?" and (b) "how good is the assumption that the large particles, assumed to be unburnt fuel are spherical?" All the analysis considered so far assumes spherical particles, but because of the high Weber numbers involved, distortion of, and even breakup of, the particles must be considered. Preliminary calculations using diffraction theory were made for a cylindrical particle with a length-to-diameter ratio (L/D) of 3 to indicate the significance of distortion on particle size. A rough estimate is that for both the visibility and the intensity measurements, an overestimate of the particle size by a factor of about 2 would result if spherical particles were assumed when actually cylinders of equal volume with an $L/D = 3$ were present. The possibility of distortion and breakup of liquid drops and the interpretation of the scattered light signals need further consideration. Another question to be considered is "How much evaporation should be expected for burning and nonburning flows?"

Additional measurements should be made to confirm the techniques that were used, both because in the backscattering region the visibility technique may be an effective way to measure the larger sized particles that seem to be present in the combustor and because of the ease (in many cases) of the actual physical placement of the instrument. Sufficient diagnostic techniques should be used to ensure that a reasonable accounting can be made for the total number of particles in the flow. A simple experiment using the diffraction pattern of the particle could be well employed to determine whether the particles are spherical or distorted spheres.

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APPENDIX A

FORTRAN PROGRAM FOR CALCULATING THE VISIBILITY AND THE SCATTERED INTENSITY FOR A SPHERICAL PARTICLE, USING THE DIFFRACTION APPROXIMATION

```
*LEVEL 2.3.0 (JUNE 78)                    OS/360  FORTRAN H EXTENDED          DATE 82.292/15.25.16        PAGE   1

REQUESTED OPTIONS: XREF,MAP,OPT=0,GOSTMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
                   SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

                    C   PROGRAM CALCULATES THE VISIBILITY AND SCATTERED INTENSITY USING
                    C   THE DIFFRACTION APPROXIMATION FOR SPHERICAL PARTICLES.
                    C     SCALE FACTOR ALPHA
                    C     X(1)=THETA
                    C     X(2)=PHI
                    C     TMIN,TMAX,=MIN ANGLE RADS(THETA) AND MAX FOR COLLECTING APERTURE
                    C     A=APERTURE RADIUS(MM),Z=FOCAL LENGTH (MM)
                    C   APERTURE IS CENTERED IN XZ PLANE.
                    C     AL=ALPHA WHERE A=PARTICLE RADIUS (MICRONS)
                    C     GAMMA EQUALS ONE-HALF THE BEAM CROSSING ANGLE
                    C     EQUATION RELATING PHI AND THETA FOR THE APERTURE IS:
                    C     COS(PHI)=(A+Z*TMIN)**2-A**2+ (Z*THETA)**2/2*(A+Z*TMIN)*Z*THETA
                    C     THE EQUATION FOR THE RELATIONSHIP BETWEEN PHI AND THETA IS:
                    C     COS(PHI)=COS(A/Z)-COS(THETA)*COS(A/Z+TMIN)/SIN(THETA)*SIN(A/Z+TMIN
                    C
                    C
  ISN 0002                IMPLICIT REAL*8(A-H,O-Z)
  ISN 0003                DIMENSION SP(30)
  ISN 0004                COMMON/INPUT/AL,WAVE,K,OUT
  ISN 0005                COMMON/LIMITS/ TMIN,TMAX,A,Z,C1,C2
  ISN 0006                COMMON/LOGCOM/ONCE
  ISN 0007                COMMON/DIAG/PHIM
  ISN 0008                LOGICAL ONCE
                    C
  ISN 0009                LOGICAL OUT
  ISN 0010                OUT=.FALSE.
                    C
  ISN 0011                READ(5,*,END=99) NSP
  ISN 0012                READ(5,*)  (SP(I),I=1,NSP)
  ISN 0013                PRINT 3, NSP,(SP(I),I=1,NSP)
  ISN 0014          3     FORMAT (I5/(10F10.3))
  ISN 0015             20 CONTINUE
  ISN 0016                PRINT 1
  ISN 0017              1 FORMAT('1')
  ISN 0018                READ(5,*,END=99) TMIN,TMAX,A, Z,WAVE
  ISN 0019                PHIM=0.0D0
  ISN 0020                ONCE=.FALSE.
  ISN 0021                C1=A/Z
  ISN 0022                C2=C1+TMIN
  ISN 0023                PRINT 9
  ISN 0024              9 FORMAT(' 0 TMIN,     TMAX,       A,        Z,        WAVE')
  ISN 0025                PRINT 5,TMIN,TMAX,A,Z,WAVE
  ISN 0026          5     FORMAT ('0',1P6G14.6)
  ISN 0027                DO 10 LX=1,NSP
  ISN 0028                AL=SP(LX)
                    C
  ISN 0029                CALL ZMINT
                    C
  ISN 0030          10    CONTINUE
  ISN 0031                GOTO 20
  ISN 0032             99 STOP
  ISN 0033                END
```

```
*LEVEL 2.3.0 (JUNE 78)            MAIN          OS/360  FORTRAN H EXTENDED              DATE 82.292/15.25.16         PAGE   2

                           *****F O R T R A N    C R O S S    R E F E R E N C E    L I S T I N G*****
SYMBOL   INTERNAL STATEMENT NUMBERS
A        0005   0018   0021   0025
I        0012   0012   0012   0013   0013   0013
K        0004
Z        0005   0018   0021   0025
AL       0004   0028
C1       0005   0021   0022
C2       0005   0022
LX       0027   0028
SP       0003   0012   0013   0028
NSP      0011   0012   0013   0013   0027
OUT      0004   0009   0010
ONCE     0006   0008   0020
PHIM     0007   0019
TMAX     0005   0018   0025
TMIN     0005   0018   0022   0025
WAVE     0004   0018   0025
ZMINT    0029

                           *****F O R T R A N    C R O S S    R E F E R E N C E    L I S T I N G*****
 LABEL    DEFINED    REFERENCES
    1     0017       0016
    3     0014       0013
    5     0026       0025
    9     0024       0023
   10     0030       0027
   20     0015       0031
   99     0032       0011   0018

                                          /    MAIN /     SIZE OF PROGRAM 000426 HEXADECIMAL BYTES

      NAME    TAG   TYPE  ADD.        NAME    TAG   TYPE  ADD.        NAME    TAG   TYPE  ADD.        NAME    TAG   TYPE  ADD.
       A SF    C    R*8   000010         I F        I*4   0000E0         K      C   I*4   NR            Z SF    C   R*8   000018
      AL S     C    R*8   000000       C1 SF   C    R*8   000020       C2 S     C   R*8   000028       LX SF        I*4   0000E4
      SP SF         R*8   0000F0      NSP SF        I*4   0000E8      OUT S     C   L*4   000014     ONCE S     C   L*4   000000
    PHIM S     C    R*8   000000     TMAX SF   C    R*8   000008     TMIN SF    C   R*8   000000     WAVE SF    C   R*8   000008
   ZMINT SF   XF          000000    IBCOM#  F  XF   L*4   000000    LDFIO#  F  XF   I*4   000000

                                  *****  COMMON INFORMATION  *****

    NAME OF COMMON BLOCK  * INPUT*   SIZE OF BLOCK    000018 HEXADECIMAL BYTES

   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
         AL   R*8    000000           WAVE  R*8    000008              K  I*4    000010 NR        OUT  L*4    000014

    NAME OF COMMON BLOCK  *LIMITS*   SIZE OF BLOCK    000030 HEXADECIMAL BYTES

   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
       TMIN   R*8    000000           TMAX  R*8    000008              A  R*8    000010             Z  R*8    000018
         C1   R*8    000020             C2  R*8    000028

    NAME OF COMMON BLOCK  *LOGCOM*   SIZE OF BLOCK    000004 HEXADECIMAL BYTES
```

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*LEVEL 2.3.0 (JUNE 78)          MAIN          OS/360   FORTRAN H EXTENDED           DATE 82.292/15.25.16       PAGE    3

       VAR. NAME   TYPE   REL. ADDR.    VAR. NAME   TYPE   REL. ADDR.    VAR. NAME   TYPE   REL. ADDR.    VAR. NAME   TYPE   REL. ADDR.
           ONCE    L*4     000000

         NAME OF COMMON BLOCK  *  DIAG*   SIZE OF BLOCK    000008 HEXADECIMAL BYTES

       VAR. NAME   TYPE   REL. ADDR.    VAR. NAME   TYPE   REL. ADDR.    VAR. NAME   TYPE   REL. ADDR.    VAR. NAME   TYPE   REL. ADDR.
           PHIM    R*8     000000

  SOURCE STATEMENT LABELS

    LABEL   ISN   ADDR             LABEL   ISN   ADDR             LABEL   ISN   ADDR             LABEL   ISN   ADDR
       20    15  0002D4               10    30  0003DC               99    32  0003F8

  COMPILER GENERATED LABELS

    LABEL   ISN   ADDR             LABEL   ISN   ADDR             LABEL   ISN   ADDR             LABEL   ISN   ADDR
   100000     1  00022C           100001    11  000238           100002    11  00024C           100003    12  000270
   100004    12  000296           100007    18  0002E8           100008    18  0002FC           100009    28  0003BC
   100010    31  0003F2

  FORMAT STATEMENT LABELS

    LABEL   ISN   ADDR             LABEL   ISN   ADDR             LABEL   ISN   ADDR             LABEL   ISN   ADDR
        3    14  000028                1    17  000035                9    24  00003A                5    26  00006D

*OPTIONS IN EFFECT*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

*OPTIONS IN EFFECT*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

*STATISTICS*     SOURCE STATEMENTS =      32, PROGRAM SIZE =      1062, SUBPROGRAM NAME =  MAIN

*STATISTICS*  NO  DIAGNOSTICS GENERATED

****** END OF COMPILATION ******                                        108K BYTES OF CORE NOT USED
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*LEVEL 2.3.0 (JUNE 78)                    OS/360   FORTRAN H EXTENDED          DATE 82.292/15.25.16        PAGE    1

REQUESTED OPTIONS: XREF,MAP,OPT=0,GOSTMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
                   SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

   ISN 0002              SUBROUTINE ZMINT                                                  ZMIN  10
                C                                                                          ZMIN  20
                C                                                                          ZMIN  30
   ISN 0003              IMPLICIT REAL*8(A-H,O-Z)                                          ZMIN  40
   ISN 0004              DIMENSION I(2),ZZ(2)                                              ZMIN  50
   ISN 0005              COMMON/INPUT/AL,WAVE,K,OUT                                        ZMIN  60
   ISN 0006              EXTERNAL XLOW,XUPP,FUNEV                                          ZMIN  70
   ISN 0007              LOGICAL OUT                                                       ZMIN  80
   ISN 0008              I(1)=1                                                            ZMIN  90
   ISN 0009              I(2)=1                                                            ZMIN 100
   ISN 0010              CC=1.0141358D-10                                                  ZMIN 110
   ISN 0011              DO 33 K=1,2                                                       ZMIN 120
   ISN 0012              OUT=.FALSE.                                                       ZMIN 130
   ISN 0013              Z=XMINT(3,2,I,XLOW,XUPP,FUNEV)                                    ZMIN 140
                C        INCIDENT POWER IS THE ACTUAL LASER POWER.THE FACTOR OF2 RESULTING ZMIN 150
                C        FROM THE BEAM SPLITTING IS ACOUNTED FOR IN THE INTEGRATION OVER   ZMIN 160
                C        ONLY ONE-HALF THE APERTURE.                                       ZMIN 170
   ISN 0014              ZZ(K)=CC*Z*(AL**4)                                                ZMIN 180
   ISN 0015           33 CONTINUE                                                          ZMIN 190
   ISN 0016              V=(ZZ(1)-ZZ(2))/(ZZ(1)+ZZ(2))                                     ZMIN 200
   ISN 0017              PM=(ZZ(1)+ZZ(2))/2                                                ZMIN 210
   ISN 0018              PRINT 1,ZZ(1),ZZ(2),PM                                            ZMIN 220
   ISN 0019            1 FORMAT('0 COLLECTED POWER (P/I),MAX='     1PG14.6,                ZMIN 230
                        1' MIN= ',   1PG14.6      ,'     MEAN='     1PG14.6        )       ZMIN 240
   ISN 0020              PRINT 3,V                                                         ZMIN 250
   ISN 0021            3 FORMAT('0 VISIBILITY=',      1PG20.8)                             ZMIN 260
   ISN 0022              RETURN                                                            ZMIN 270
   ISN 0023              END                                                               ZMIN 280

                    *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
SYMBOL   INTERNAL STATEMENT NUMBERS
I        0004  0008  0009  0013
K        0005  0011  0014
V        0016  0020
Z        0013  0014
AL       0005  0014
CC       0010  0014
PM       0017  0018
ZZ       0004  0014  0016  0016  0016  0016  0017  0017  0018  0018
OUT      0005  0007  0012
WAVE     0005
XLOW     0006  0013
XUPP     0006  0013
FUNEV    0006  0013
XMINT    0013
ZMINT    0002

                    *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
 LABEL    DEFINED    REFERENCES
    1     0019       0018
    3     0021       0020
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*LEVEL 2.3.0 (JUNE 78)         ZMINT          OS/360  FORTRAN H EXTENDED          DATE 82.292/15.25.16       PAGE   2

                        *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
 LABEL   DEFINED   REFERENCES
   33     0015      0011

                                                 /   ZMINT /     SIZE OF PROGRAM 0002D8 HEXADECIMAL BYTES

     NAME    TAG   TYPE  ADD.        NAME    TAG   TYPE  ADD.        NAME    TAG   TYPE  ADD.        NAME    TAG   TYPE  ADD.
        I SFA      I*4   000138         K SF   C   I*4   000010         V SF       R*8   000110         Z SF       R*8   000118
       AL  F   C   R*8   000000        CC SF       R*8   000120        PM SF       R*8   000128        ZZ SF       R*8   000140
      OUT S    C   L*4   000014      WAVE      C   R*8     NR        XLOW   A XF   R*8   000000      XUPP   A XF   R*8   000000
    FUNEV   A XF   R*8   000000     XMINT  F  XF   R*8   000000     ZMINT          R*8   000130    IBCOM#     XF   I*4   000000

                                          *****  COMMON INFORMATION   *****

      NAME OF COMMON BLOCK  * INPUT*   SIZE OF BLOCK    000018 HEXADECIMAL BYTES

     VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.
            AL  R*8    000000            WAVE  R*8    000008 NR            K  I*4    000010             OUT  L*4    000014


 SOURCE STATEMENT LABELS

   LABEL  ISN  ADDR          LABEL  ISN  ADDR          LABEL  ISN  ADDR          LABEL  ISN  ADDR
      33   15  000208
 COMPILER GENERATED LABELS

   LABEL  ISN  ADDR          LABEL  ISN  ADDR          LABEL  ISN  ADDR          LABEL  ISN  ADDR
  100001    2  000190       100002   12  0001B4       100003   16  000222
 FORMAT STATEMENT LABELS

   LABEL  ISN  ADDR          LABEL  ISN  ADDR          LABEL  ISN  ADDR          LABEL  ISN  ADDR
       1   19  000028            3   21  00006A
*OPTIONS IN EFFECT*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

*OPTIONS IN EFFECT*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

*STATISTICS*    SOURCE STATEMENTS =      22, PROGRAM SIZE =      728, SUBPROGRAM NAME = ZMINT

*STATISTICS*  NO  DIAGNOSTICS GENERATED

****** END OF COMPILATION ******                                        108K BYTES OF CORE NOT USED
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*LEVEL 2.3.0 (JUNE 78)                     OS/360   FORTRAN H EXTENDED            DATE 82.292/15.25.16        PAGE    1

REQUESTED OPTIONS: XREF,MAP,OPT=0,GOSTMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
                   SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

   ISN 0002          FUNCTION XLOW (J, X)                                                    FUNC  10
             C                                                                               FUNC  20
   ISN 0003          IMPLICIT REAL*8(A-H,O-Z)                                                FUNC  30
   ISN 0004          COMMON/LIMITS/ TMIN,TMAX,A,Z,C1,C2                                      FUNC  40
   ISN 0005          XLOW=0.0D0                                                              FUNC  50
   ISN 0006          IF(J.EQ.1) XLOW=TMIN                                                    FUNC  60
   ISN 0008          IF(TMIN .LT.  0.0D0 ) XLOW=0.0D0                                        FUNC  70
   ISN 0010          RETURN                                                                  FUNC  80
   ISN 0011          END                                                                     FUNC  90

                    *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
SYMBOL  INTERNAL STATEMENT NUMBERS
A       0004
J       0002  0006
X       0002
Z       0004
C1      0004
C2      0004
TMAX    0004
TMIN    0004  0006  0008
XLOW    0002  0005  0006  0008

                                                    /      XLOW /     SIZE OF PROGRAM 00012A HEXADECIMAL BYTES

      NAME     TAG   TYPE  ADD.         NAME    TAG    TYPE  ADD.        NAME    TAG   TYPE   ADD.        NAME     TAG   TYPE  ADD.
        A       C    R*8    NR            J            I*4   000084        X           R*8   000088         Z        C   R*8    NR
       C1       C    R*8    NR           C2      C     R*8    NR         TMAX     C    R*8    NR         TMIN  F    C   R*8   000000
      XLOW S         R*8   000090
                                   *****  COMMON INFORMATION   *****

       NAME OF COMMON BLOCK  *LIMITS*   SIZE OF BLOCK    000030 HEXADECIMAL BYTES

      VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.
          TMIN   R*8    000000           TMAX   R*8    000008 NR           A   R*8    000010 NR           Z   R*8    000018 NR
            C1   R*8    000020 NR          C2   R*8    000028 NR


 COMPILER GENERATED LABELS

   LABEL  ISN   ADDR            LABEL  ISN   ADDR           LABEL  ISN   ADDR            LABEL  ISN   ADDR
  100001    2  0000B8          100002    7  0000CE         100003    8  0000DA          100004    9  0000EA
  100005   10  0000F2

*OPTIONS IN EFFECT*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

*OPTIONS IN EFFECT*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

*STATISTICS*     SOURCE STATEMENTS =      10, PROGRAM SIZE =      298, SUBPROGRAM NAME =  XLOW
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*LEVEL 2.3.0 (JUNE 78)                 OS/360  FORTRAN H EXTENDED           DATE 82.292/15.25.16        PAGE   2
*STATISTICS*  NO  DIAGNOSTICS GENERATED
****** END OF COMPILATION ******                                    108K BYTES OF CORF NOT USED
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*LEVEL 2.3.0 (JUNE 78)                    OS/360   FORTRAN H EXTENDED           DATE 82.292/15.25.17        PAGE   1

REQUESTED OPTIONS: XREF,MAP,OPT=0,GOSTMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
                   SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

  ISN 0002          FUNCTION XUPP (J, X)                                              FUNC  10
              C                                                                       FUNC  20
  ISN 0003          IMPLICIT REAL*8(A-H,O-Z)                                          FUNC  30
  ISN 0004              DIMENSION  X(2)                                               FUNC  40
  ISN 0005          COMMON/LOGCOM/ONCE                                                FUNC  50
  ISN 0006          COMMON/LIMITS/ TMIN,TMAX,A,Z,C1,C2                                FUNC  60
  ISN 0007          LOGICAL ONCE                                                      FUNC  70
  ISN 0008          GO TO(1,2),J                                                      FUNC  80
  ISN 0009    1     XUPP=TMAX                                                         FUNC  90
  ISN 0010          RETURN                                                            FUNC 100
  ISN 0011        2 XUPP=0.0D0                                                        FUNC 110
  ISN 0012          IF ( TMIN .LT. 0.0D0 ) GOTO 30                                    FUNC 120
  ISN 0014          IF (X(1).EQ.0.0) RETURN                                           FUNC 130
  ISN 0016          XN=DCOS(C1)-DCOS(X(1))*DCOS(C2)                                   FUNC 140
  ISN 0017          XD DSIN(X(1))*DSIN(C2)                                            FUNC 150
  ISN 0018          XUPP=DARCOS(XN/XD)                                                FUNC 160
  ISN 0019          GOTO 40                                                           FUNC 170
  ISN 0020       30 XUPP=3.1415900                                                    FUNC 180
  ISN 0021       40 CONTINUE                                                          FUNC 190
  ISN 0022          IF (ONCE) GOTO110                                                 FUNC 200
  ISN 0024          ONCE=.TRUE.                                                       FUNC 210
  ISN 0025          PRINT4,X(1),XUPP                                                  FUNC 220
  ISN 0026        4 FORMAT(' XUPP=',1PG20.8)                                          FUNC 230
  ISN 0027      110 CONTINUE                                                          FUNC 240
  ISN 0028          RETURN                                                            FUNC 250
  ISN 0029          END                                                               FUNC 260

                 *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
SYMBOL   INTERNAL STATEMENT NUMBERS
A        0006
J        0002  0008
X        0002  0004  0014  0016  0017  0025
Z        0006
C1       0006  0016
C2       0006  0016  0017
XD       0017  0018
XN       0016  0018
DCOS     0016  0016  0016
DSIN     0017  0017
ONCE     0005  0007  0022  0024
TMAX     0006  0009
TMIN     0006  0012
XUPP     0002  0009  0011  0018  0020  0025
DARCOS   0018

                 *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
 LABEL    DEFINED    REFERENCES
    1      0009       0008
    2      0011       0008
    4      0026       0025
   30      0020       0012
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*LEVEL 2.3.0 (JUNE 78)          XUPP          OS/360  FORTRAN H EXTENDED          DATE 82.292/15.25.17       PAGE   2

                    *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
 LABEL    DEFINED    REFERENCES
   40     0021       0019
  110     0027       0022

                                                  /   XUPP /    SIZE OF PROGRAM 0002F2 HEXADECIMAL BYTES

     NAME    TAG   TYPE  ADD.         NAME    TAG   TYPE  ADD.        NAME    TAG   TYPE  ADD.         NAME    TAG   TYPE  ADD.
        A      C   R*8     NR            J  F       I*4   0000BC         X  FA XR   R*8   000000          Z      C   R*8     NR
       C1   FA C   R*8   000020         C2  FA C    R*8   000028        XD SFA      R*8   0000C0         XN SFA    R*8   0000C8
     DCOS   F XF   R*8   000000       DSIN  F XF    R*8   000000      ONCE S    C   L*4   000000       TMAX  F  C  R*8   000008
     TMIN      C   R*8   000000       XUPP SF       R*8   0000D0    DARCOS  F  XF   R*8   000000     IBCOM#    XF  L*4   000000

                                      *****  COMMON INFORMATION   *****

      NAME OF COMMON BLOCK  *LOGCOM*   SIZE OF BLOCK    000004 HEXADECIMAL BYTES

     VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
         ONCE   L*4    000000

      NAME OF COMMON BLOCK  *LIMITS*   SIZE OF BLOCK    000030 HEXADECIMAL BYTES

     VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
         TMIN   R*8    000000          TMAX  R*8    000008             A  R*8    000010 NR           Z  R*8    000018 NR
           C1   R*8    000020            C2  R*8    000028


  SOURCE STATEMENT LABELS

    LABEL  ISN  ADDR            LABEL  ISN  ADDR            LABEL  ISN  ADDR            LABEL  ISN  ADDR
        1    9  00015A              2   11  00016E             30   20  00025E             40   21  000266
      110   27  0002AC

  COMPILER GENERATED LABELS

    LABEL  ISN  ADDR            LABEL  ISN  ADDR            LABEL  ISN  ADDR            LABEL  ISN  ADDR
   100001    2  000140         100003   14  000186         100004   15  000196         100005   16  00019E
   100006   24  000278

  FORMAT STATEMENT LABELS

    LABEL  ISN  ADDR            LABEL  ISN  ADDR            LABEL  ISN  ADDR            LABEL  ISN  ADDR
        4   26  000028

*OPTIONS IN EFFECT*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

*OPTIONS IN EFFECT*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

*STATISTICS*    SOURCE STATEMENTS =      28, PROGRAM SIZE =      754, SUBPROGRAM NAME =  XUPP

*STATISTICS*  NO  DIAGNOSTICS GENERATED

****** END OF COMPILATION ******                                   108K BYTES OF CORE NOT USED
```

```
*LEVEL 2.3.0 (JUNE 78)                    OS/360   FORTRAN H EXTENDED              DATE 82.292/15.25.17        PAGE   1

REQUESTED OPTIONS: XREF,MAP,OPT=0,GOSTMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
                   SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

  ISN 0002           FUNCTION FUNEV(J,X)                                                    FUNC  10
               C                                                                            FUNC  20
  ISN 0003           IMPLICIT REAL*8(A-H,O-Z)                                               FUNC  30
  ISN 0004           COMMON/INPUT/AL,WAVE,K                                                 FUNC  40
  ISN 0005           DIMENSION X(2),E(2),W(2)                                               FUNC  50
  ISN 0006           GO TO (1,2),J                                                          FUNC  60
  ISN 0007        1  FUNEV=1.0D0                                                            FUNC  70
  ISN 0008           RETURN                                                                 FUNC  80
               C                                                                            FUNC  90
  ISN 0009         2 CALL BESEL2 (X,W)                                                      FUNC 100
  ISN 0010           FUNEV=W(K)*DSIN(X(1))                                                  FUNC 110
  ISN 0011           RETURN                                                                 FUNC 120
  ISN 0012           END                                                                    FUNC 130

                 *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
SYMBOL   INTERNAL STATEMENT NUMBERS
E        0005
J        0002  0006
K        0004  0010
W        0005  0009  0010
X        0002  0005  0009  0010
AL       0004
DSIN     0010
WAVE     0004
FUNEV    0002  0007  0010
BESEL2   0009

                 *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
 LABEL   DEFINED   REFERENCES
   1     0007      0006
   2     0009      0006

                                       /   FUNEV /     SIZE OF PROGRAM 0001BC HEXADECIMAL BYTES

   NAME     TAG    TYPE   ADD.       NAME     TAG    TYPE   ADD.      NAME    TAG    TYPE   ADD.       NAME    TAG    TYPE   ADD.
      E            R*8     NR           J   F        I*4    00009C       K   F   C    I*4    000010        W SFA        R*8   0000A8
      X SFA XR     R*8    000000       AL        C   R*8     NR       DSIN   F   XF   R*8    000000     WAVE       C   R*8     NR
  FUNEV S          R*8    0000A0   BESEL2 SF  XF            000000

                             *****  COMMON INFORMATION   *****

    NAME OF COMMON BLOCK  * INPUT*   SIZE OF BLOCK     000014 HEXADECIMAL BYTES

   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
        AL    R*8    000000 NR       WAVE   R*8    000008 NR          K   I*4    000010


  SOURCE STATEMENT LABELS
```

```
*LEVEL 2.3.0 (JUNE 78)                     OS/360   FORTRAN H EXTENDED          DATE 82.292/15.25.17       PAGE   2

    LABEL   ISN   ADDR           LABEL   ISN   ADDR           LABEL   ISN   ADDR           LABEL   ISN   ADDR
        1     7  000112              2     9  000122

  COMPILER GENERATED LABELS

    LABEL   ISN   ADDR           LABEL   ISN   ADDR           LABEL   ISN   ADDR           LABEL   ISN   ADDR
   100001     2  0000F8

*OPTIONS IN EFFECT*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

*OPTIONS IN EFFECT*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

*STATISTICS*     SOURCE STATEMENTS =       11, PROGRAM SIZE =       444, SUBPROGRAM NAME = FUNEV

*STATISTICS*  NO  DIAGNOSTICS GENERATED

****** END OF COMPILATION ******                                    108K BYTES OF CORE NOT USED
```

```
*LEVEL 2.3.0 (JUNE 78)                    OS/360   FORTRAN H EXTENDED              DATE 82.292/15.25.17        PAGE    1

REQUESTED OPTIONS: XREF,MAP,OPT=0,GOSTMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
                   SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

   ISN 0002            SUBROUTINE BESEL2(X,W)
                 C
                 C       COMPUTE BESSEL FUNCTION FOR EACH ALPHA
                 C     FOR GAMMA =1.03 DGREES USE CARD 1
                 C     CARD 1 REAL*8 GSC(2,2)/.01796900, 0.999838D0, -0.017960D0,0.999838D0
                 C     FOR GAMMA=.645 DEGREES USE CARD 2
                 C     CARD 2 REAL*8 GSC(2,2)/ 0.011249D0,0.999367D0,-0.011249D0,0.9999367D
                 C
                 C
                 C
   ISN 0003            IMPLICIT REAL*8(A-H,O-Z)
   ISN 0004               REAL*8 GSC(2,2)/ 0.011249D0,0.999367D0,-0.011249D0,0.9999367D0/
   ISN 0005            COMMON/INPUT/AL,WAVE,K,OUT
   ISN 0006            COMMON/PARM/RAD,FN
   ISN 0007            COMMON/DIAG/PHIM
   ISN 0008            DIMENSION X(2),E(2),W(2) , ARG(2)
   ISN 0009            DIMENSION CSTH(2,2)
   ISN 0010            DIMENSION PSI(2),E1(2),E2(2)
   ISN 0011            DIMENSION PHI(2)
                 C
   ISN 0012            LOGICAL ONCE/.FALSE./
   ISN 0013            LOGICAL OUT
   ISN 0014            IF (ONCE) GOTO110
   ISN 0016            ONCE=.TRUE.
                 C
                 C
   ISN 0017            PI = 4.0D0 * DATAN( 1.0D0)
   ISN 0018            DEG = 180.0 / PI
   ISN 0019            GAM=DARSIN(GSC(1,1))
   ISN 0020            SGAM = GSC(1,1)
   ISN 0021            CGAM = DCOS(GAM)
                 C     FN=INTERFERENCE FRINGE IN MICRONS
   ISN 0022            FN=((WAVE)/GSC(1,1))/2
   ISN 0023        110 CONTINUE
                 C
   ISN 0024            SX1=DSIN(X(1))
   ISN 0025            CX1=DCOS(X(1))
   ISN 0026            SX2=DSIN(X(2))
   ISN 0027            CX2=DCOS(X(2))
                 C
   ISN 0028            SGN2=1.0D0
                 C
   ISN 0029            DO 45 J=1,2
   ISN 0030            SGN=(3-2*J)
   ISN 0031            IF( K.EQ.2 .AND. J. EQ. 2) SGN2=-1.0D0
                 C     CSTH(K,J)=CX1*DCOS(GAM)+SX1*SX2*DSIN(GAM)*SGN
   ISN 0033            CSTH(K,J)=CX1* CGAM     +SX1*SX2* SGAM * SGN
   ISN 0034            ARG(J)=DARCOS(CSTH(K,J))
   ISN 0035            IF(ARG(J) .EQ. 0.0D0) ARG(J) = 0.0001D0
                 C
                 C     ANGLE IN RADS BETWEEN OFFSET SCATTERING PLANES ANDREF PLANE
                 C     PSI(J)=DARSIN((DSIN(GAM)*CX2)/DSIN(ARG(J)))
   ISN 0037            PSI(J)=DARSIN((  SGAM    *CX2)/DSIN(ARG(J)))
```

```
                 C
                 C
                 C
                 C     COMPUTE THE BESSEL FUNCTION J1(AA).DIVIDE BY AA LATER.
ISN 0038               AA=AL*DSIN(ARG(J))
ISN 0039               CALL DBJ1(AA,BJ1,IER)
ISN 0040               IF(AA.EQ.0) BJ1=1
ISN 0042               IF(AA.NE.0) BJ1=BJ1/AA
                 C     BJ1=J1(X)/X
                 C     CONVERSION FOR VERTICALLY POLARIZED ILLUMINATION
                 C
ISN 0044               PHI(J)=X(2)+(2*J-3)*DATAN(DTAN(PSI(J))*CX1)
ISN 0045               E1(J)=BJ1*DSIN(PHI(J))
ISN 0046               E2(J)=BJ1*DCOS(PHI(J))
                 C
ISN 0047               IF (PHIM .LT. APHI) PHIM=APHI
ISN 0049               IF(OUT) GOTO 45
ISN 0051               PRINT 3
ISN 0052             3 FORMAT('0      ARG,            BJ1,         SGN,          SGN2')
ISN 0053               PRINT 1,ARG(J),BJ1,SGN,SGN2
ISN 0054             1 FORMAT('0', 1P4G14.6)
ISN 0055            45 CONTINUE
                 C
                 C
                 C     FIELD IN REFERENCE SCATTERING PLANE E2
ISN 0056               E(2) = E2(1)*DCOS(PSI(1)) - E1(1)*DSIN(PSI(1)) +
                      1   (E2(2)*DCOS(PSI(2)) + E1(2)*DSIN(PSI(2))) * SGN2
                 C
                 C     COMPONENT PERPINDICULAR TO REFERENCE SCATTERING PLANE E1
                 C
ISN 0057               E(1) = -E2(1)*DSIN(PSI(1)) - E1(1)*DCOS(PSI(1))  +
                      1   (E2(2)*DSIN(PSI(2)) - E1(2)*DCOS(PSI(2))) * SGN2
                 C
                 C     INTENSITY AT A GIVEN POINT ON THE DETECTOR
                 C
ISN 0058               W(K)=E(2)**2+E(1)**2
                 C     THIS ASSUMES THE THE TWO POLARIZATIONS ARE IN OR OUT OF PHASE.
                 C
                 C
ISN 0059               IF (OUT) GOTO 35
ISN 0061               OUT=.TRUE.
                 C
ISN 0062               DIA=(AL*WAVE)/PI
ISN 0063               ATETA=X(1)*DEG
ISN 0064               APHI=X(2)*DEG
ISN 0065               PRINT 5
ISN 0066             5 FORMAT(' FN ,        DIA   ,     E(1),          E(2),
                      1    W(K),         K')
ISN 0067               PRINT 7,FN,DIA,E(1),E(2),W(K),K
ISN 0068             7 FORMAT ('0', 1P5G14.6,I5)
ISN 0069               PRINT 9
ISN 0070             9 FORMAT('0        PSI(1),         PSI(2),         PHI(1)    ,
                      1           PHI(2)')
ISN 0071               PRINT 13,PSI(1),PSI(2),PHI(1),PHI(2)
ISN 0072            13 FORMAT('0',1P4G14.6)
ISN 0073               PRINT 21
ISN 0074            21 FORMAT('0      X(1)         X(2)          ARG          AA
                      1    BJ1         ATETA          APHI          PHIM')
```

```
*LEVEL 2.3.0 (JUNE 78)          BESEL2          OS/360  FORTRAN H EXTENDED          DATE 82.292/15.25.17        PAGE    3

    ISN 0075            PRINT 17,X(1),X(2),ARG(1),AA,BJ1,ATETA,APHI,PHIM                  BESE1120
    ISN 0076            PRINT 18, ARG(2)                                                  BESE1130
    ISN 0077         17 FORMAT('0', 1P8G14.6)                                             BESE1140
    ISN 0078         18 FORMAT( T29,1PG14.6)                                              BESE1150
                  C                                                                        BESE1160
                  C                                                                        BESE1170
    ISN 0079      35    RETURN                                                            BESE1180
    ISN 0080            END                                                               BESE1190

                         *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
SYMBOL   INTERNAL STATEMENT NUMBERS
E        0008 0056 0057 0058 0058 0067 0067
J        0029 0030 0031 0033 0034 0034 0035 0035 0037 0037 0038 0044 0044 0044 0045 0045 0046 0046 0053
K        0005 0031 0033 0034 0058 0067 0067
W        0002 0008 0058 0067
X        0002 0008 0024 0025 0026 0027 0044 0063 0064 0075 0075
AA       0038 0039 0040 0042 0042 0075
AL       0005 0038 0062
E1       0010 0045 0056 0056 0057 0057
E2       0010 0046 0056 0056 0057 0057
FN       0006 0022 0067
PI       0017 0018 0062
ARG      0008 0034 0035 0035 0037 0038 0053 0075 0076
BJ1      0039 0040 0042 0042 0045 0046 0053 0075
CX1      0025 0033 0044
CX2      0027 0037
DEG      0018 0063 0064
DIA      0062 0067
GAM      0019 0021
GSC      0004 0004 0019 0020 0022
IER      0039
OUT      0065 0013 0049 0059 0061
PHI      0011 0044 0045 0046 0071 0071
PSI      0010 0037 0044 0056 0056 0056 0056 0057 0057 0057 0057 0071 0071
RAD      0006
SGN      0030 0033 0053
SX1      0024 0033
SX2      0026 0033
APHI     0047 0047 0064 0075
CGAM     0021 0033
CSTH     0009 0033 0034
DBJ1     0039
DCOS     0021 0025 0027 0046 0056 0056 0057 0057
DSIN     0024 0026 0037 0038 0045 0056 0056 0057 0057
DTAN     0044
ONCE     0012 0012 0014 0016
PHIM     0007 0047 0047 0075
SGAM     0020 0033 0037
SGN2     0028 0031 0053 0056 0057
WAVE     0005 0022 0062
ATETA    0063 0075
DATAN    0017 0044
BESEL2   0002
DARCOS   0034
DARSIN   0019 0037
```

```
*LEVEL 2.3.0 (JUNE 78)        BESEL2          OS/360   FORTRAN H EXTENDED              DATE 82.292/15.25.17        PAGE    4

                                  *****F O R T R A N     C R O S S     R E F E R E N C E     L I S T I N G*****
LABEL     DEFINED      REFERENCES
   1      0054         0053
   3      0052         0051
   5      0066         0065
   7      0068         0067
   9      0070         0069
  13      0072         0071
  17      0077         0075
  18      0078         0076
  21      0074         0073
  35      0079         0059
  45      0055         0029   0049
 110      0023         0014

                                                         /   BESEL2 /     SIZE OF PROGRAM 0000DC HEXADECIMAL BYTES

    NAME      TAG    TYPE   ADD.        NAME      TAG   TYPE   ADD.        NAME      TAG   TYPE   ADD.        NAME      TAG   TYPE   ADD.
       E SF          R*8    000308         J SFA        I*4    000274         K  FA  C   I*4    000010         W SF  XR     R*8    000000
       X  FA XR      R*8    000000        AA SFA        R*8    000280        AL  F   C   R*8    000000        E1 SF         R*8    000318
      E2 SF          R*8    000328        FN SF   C     R*8    000008        PI SF       R*8    000288       ARG SFA        R*8    000338
     BJ1 SFA         R*8    000290       CX1 SFA        R*8    000298       CX2 SFA      R*8    0002A0       DEG SF         R*8    0002A8
     DIA SF          R*8    0002B0       GAM SFA        R*8    0002B8       GSC  FA      R*8    000348       IER SFA        I*4    000278
     OUT S    C      L*4    000014       PHI SFA        R*8    000368       PSI SFA      R*8    000378       RAD      C     R*8      NR
     SGN SF          R*8    0002C0       SX1 SF         R*8    0002C8       SX2 SF       R*8    0002D0      APHI SF         R*8    0002D8
    CGAM SF          R*8    0002E0      CSTH SFA        R*8    000388      DBJ1 SF  XF          000000      DCOS  F  XF    R*8    000000
    DSIN  FA XF      R*8    000000      DTAN  FA XF     R*8    000000      ONCE S       L*4    00027C      PHIM SF   C    R*8    000000
    SGAM SFA         R*8    0002E8      SGN2 SF         R*8    0002F0      WAVE  F   C  R*8    000008     ATETA SF         R*8    0002F8
   DATAN  F  XF      R*8    000000    BESEL2            R*8    000300    DARCOS  F  XF  R*8    000000    DARSIN  F  XF    R*8    000000
  IBCOM#     XF      I*4    000000

                                     *****   COMMON INFORMATION    *****

      NAME OF COMMON BLOCK  * INPUT*   SIZE OF BLOCK    000018 HEXADECIMAL BYTES

   VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.
        AL    R*8    000000            WAVE  R*8    000008             K    I*4    000010           OUT   L*4    000014

      NAME OF COMMON BLOCK  *  PARM*   SIZE OF BLOCK    000010 HEXADECIMAL BYTES

   VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR  NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.
        RAD   R*8    000000 NR           FN  R*8    000008

      NAME OF COMMON BLOCK  *  DIAG*   SIZE OF BLOCK    000008 HEXADECIMAL BYTES

   VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.
        PHIM  R*8    000000

SOURCE STATEMENT LABELS

  LABEL   ISN   ADDR          LABEL   ISN   ADDR          LABEL   ISN   ADDR          LABEL   ISN   ADDR
   110     23   000504           45    55   000924           35    79   000CC0
```

```
*LEVEL 2.3.0 (JUNE 78)          BESEL2          OS/360  FORTRAN H EXTENDED          DATE 82.292/15.25.17          PAGE   5

  COMPILER GENERATED LABELS

    LABEL   ISN   ADDR        LABEL   ISN   ADDR        LABEL   ISN   ADDR        LABEL   ISN   ADDR
   100001     2  000464      100002    16  000472      100003    30  0005B0      200001    32  0005E4
   100004    32  0005F2      100005    33  0005FC      100006    36  0006A8      100007    37  0006B8
   100008    41  000770      100009    42  000778      100010    43  000784      100011    44  000790
   100012    48  0008B6      100013    49  0008C2      100014    51  0008D4      100015    56  00093A
   100016    51  000B44

  FORMAT STATEMENT LABELS

    LABEL   ISN   ADDR        LABEL   ISN   ADDR        LABEL   ISN   ADDR        LABEL   ISN   ADDR
        3    52  000028           1    54  000060           5    66  00006C           7    68  0000BC
        9    70  0000CA          13    72  000116          21    74  000122          17    77  00018F
       18    78  00019B

*OPTIONS IN EFFECT*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

*OPTIONS IN EFFECT*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

*STATISTICS*     SOURCE STATEMENTS =      79, PROGRAM SIZE =      3340, SUBPROGRAM NAME =BESEL2

*STATISTICS*  NO  DIAGNOSTICS GENERATED

****** END OF COMPILATION ******                                     92K BYTES OF CORE NOT USED

*STATISTICS*  NO  DIAGNOSTICS THIS STEP
```

```
0 TMIN,     TMAX,      A,        Z,         WAVE
   3.40000D-02   .170000       17.0000      250.000       .632800
XUPP=         .10846085
XUPP=         .65636487
      ARG,          BJ1,         SGN,         SGN2
   .105032       .360567      1.00000      1.00000
      ARG,          BJ1,         SGN,         SGN2
   .112907       .341515     -1.00000      1.00000
FN ,         DIA      ,      E(1),        E(2),             W(K),        K
   28.1269       3.02140      -.246931      .657225      .492919      1
       PSI(1),            PSI(2),        PHI(1)    ,             PHI(2)
   .100614       9.36012D-02   .259338      .452418
      X(1)          X(2)          ARG          AA            BJ1        ATETA        APHI        PHIM
   .108461       .359364      .105032      1.69001      .341515      6.21435      20.5900      .0
                               .112907
      ARG,          BJ1,         SGN,         SGN2
   .105032       .360567      1.00000      1.00000
      ARG,          BJ1,         SGN,         SGN2
   .112907       .341515     -1.00000     -1.00000
FN ,         DIA      ,      E(1),        E(2),             W(K),        K
   28.1269       3.02140     -7.07337D-03  1.76952D-02  3.63153D-04   2
       PSI(1),            PSI(2),        PHI(1)    ,             PHI(2)
   .100614       9.36012D-02   .259338      .452418
      X(1)          X(2)          ARG          AA            BJ1        ATETA        APHI        PHIM
   .108461       .359364      .105032      1.69001      .341515      6.21435      20.5900      20.5900
                               .112907
 COLLECTED POWER (P/I),MAX=   1.87184D-08 MIN=    1.03062D-11    MEAN=   9.36436D-09
 VISIBILITY=        .99889942
```

1
15.000

APPENDIX B

FORTRAN PROGRAM FOR CALCULATING THE VISIBILITY AND THE SCATTERED INTENSITY FOR A SPHERICAL PARTICLE, USING THE MIE THEORY CALCULATIONS

```
REQUESTED OPTIONS: XREF,MAP,OPT=0,GOSTMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
                   SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

                   C     MAIN DRIVER    12/23/81
                   C
                   C               MIE SCATTERING RESPONSE FOR A TWO BEAM LDV
                   C
                   C
                   C
                   C    PROGRAM CALCULATES THE VISIBILITY AND THE MEAN SCATTERED INTENSITY F
                   C    SPHERICAL PARTICLES USING THE SUPERMIDI CODE TO CALCULATE THE MIE FU
                   C
                   C    THE REFERENCE FOR SUPERMIDI IS GREHAN AND GOUEBET APPLIED OPTICS VOL
                   C    15 OCTOBER 1979,(3489) AND INTERNAL REPORT TTI/GG/79/03/20.SUPERMIDI
                   C    BE USED WITH PARTICLES HAVING LARGE IMAGINARY INDICES OF REFRACTION.
                   C
                   C
                   C
                   C    PARAMETERS: INDEX OF REFRACTION( RI-COMPLEX-FIVE VALUES);SIZE PARAM
                   C    ALPHA(KA=SP-20 VALUES);WAVELENGTH(WAVE-MICRONS);FOCAL LENGTH OF LENS
                   C    RADIUS OF APERTURE(A-MM);TMIN(MIN.ANGLE OF APERTURE-RADS);TMAX(MAX.A
                   C    APERTURE-RADS).THE APERTURE IS THE LIMITING APERTURE IN THE DETECTIO
                   C    THE APERTURE IS CIRCULAR AND CENTERED IN THE XZ PLANE.
                   C    ANGLE THETA CAN BE VARIED FROM ZERO TO 180.
                   C    ALL VALUES OF THE INPUTS ARE IN FREE FORMAT
                   C    THE INDEX OF REFRACTION OF THE MEDIUM IS SET TO 1.0
                   C
                   C
                   C
                   C
  ISN 0002              IMPLICIT REAL*8(A-H,O-Z,$)
  ISN 0003              COMPLEX*16  RI(5), INDICE
  ISN 0004              COMPLEX*16  ELEC(1000), EMAG(1000)
  ISN 0005              DIMENSION SP(20)
                   C
  ISN 0006              COMMON/INPUT/AL,WAVE,K,OUT
  ISN 0007              COMMON/LIMITS/ TMIN,TMAX,A,Z,C1,C2
  ISN 0008              COMMON /COM4/ AIRIN, INDICE
  ISN 0009              COMMON /COM5/  ALPHA
  ISN 0010              COMMON/LOGCOM/ONCE
  ISN 0011              COMMON/DIAG/PHIM
                   C
  ISN 0012              LOGICAL ONCE
  ISN 0013              LOGICAL OUT
  ISN 0014              OUT=.FALSE.
                   C
                   C
  ISN 0015              PRINT 1, NRI
  ISN 0016              READ(5,*,END=99) NRI
  ISN 0017              IF(NRI .GT. 5) GO TO 99
  ISN 0019              DO 20 I=1,NRI
  ISN 0020              READ (5,*) R1, R2
  ISN 0021              IF(DABS(R1) .GT. 100.0) GO TO 99
  ISN 0023              IF(DABS(R2) .GT. 100.0) GO TO 99
  ISN 0025              RI(I) = DCMPLX(R1,R2)
  ISN 0026           20 CONTINUE
```

```
  ISN 0027            PRINT 1, NRI, (RI(I),I=1,NRI)                              MAIN 540
  ISN 0028          1 FORMAT(I5/(F10.3,F10.6))                                   MAIN 550
  ISN 0029        2   FORMAT(    (8F10.3))                                       MAIN 560
  ISN 0030            READ(5,*,END=99) NSP                                       MAIN 570
  ISN 0031            READ(5,*)  (SP(I),I=1,NSP)                                 MAIN 580
  ISN 0032        3   FORMAT(I5/(10F10.3))                                       MAIN 590
  ISN 0033            PRINT 3, NSP,(SP(I),I=1,NSP)                               MAIN 600
  ISN 0034       1000 CONTINUE                                                   MAIN 610
  ISN 0035            READ(5,*,END=99) TMIN,TMAX,A, Z,WAVE                       MAIN 620
  ISN 0036            PHIM=0.0D0                                                 MAIN 630
  ISN 0037            ONCE=.FALSE.                                               MAIN 640
  ISN 0038            C1=A/Z                                                     MAIN 650
  ISN 0039            C2=C1+TMIN                                                 MAIN 660
  ISN 0040            PRINT 9                                                    MAIN 670
  ISN 0041          9 FORMAT(' 0 TMIN,     TMAX,      A,       Z,        WAVE')  MAIN 680
  ISN 0042            PRINT 5,TMIN,TMAX,A,Z,WAVE                                 MAIN 690
  ISN 0043      5     FORMAT ('0',1P6G14.6)                                      MAIN 700
                C                                                                MAIN 710
                C                                                                MAIN 720
  ISN 0044            DO 10 LRI=1,NRI                                            MAIN 730
  ISN 0045            INDICE=RI(LRI)                                             MAIN 740
                C                                                                MAIN 750
                C                                                                MAIN 760
  ISN 0046            DO 10 LX=1,NSP                                             MAIN 770
  ISN 0047            ALPHA=SP(LX)                                               MAIN 780
  ISN 0048            AL = ALPHA                                                 MAIN 790
                C                                                                MAIN 800
  ISN 0049            CALL MIEMAN(QEXT, QSCA,QABS, ELEC, EMAG, NCO)              MAIN 810
                C   MIEMAN IS A SUPERMIDI ROUTINE                                MAIN 820
                C                                                                MAIN 830
  ISN 0050            PRINT 7, ALPHA, INDICE, QEXT, QSCA, QABS                   MAIN 840
  ISN 0051          7 FORMAT(1H1,'MIE COEFFICIENTS FOR X = ',F10.2,', REF.INDEX = ',  MAIN 850
                     + F7.3,F10.6,1HI//5X,'QEXT = ',F10.6,', QSCA = ',F10.6,     MAIN 860
                     25X,'QABS=',F15.5)                                          MAIN 870
  ISN 0052            PRINT 8, (I, ELEC(I), EMAG(I),I=1,NCO)                     MAIN 880
  ISN 0053        8   FORMAT('0',///,(5X,I5,1P4G20.7))                           MAIN 890
                C                                                                MAIN 900
                C                                                                MAIN 910
  ISN 0054            CALL ZMINT                                                 MAIN 920
                C                                                                MAIN 930
                C   ZMINT IS AN APL INTEGRATION ROUTINE(5.01.100) AND IS NORMALLY USED TMAIN 940
                C   PROVIDE A 16 POINT GAUSSIAN QUADRATURE INTEGRATION.          MAIN 950
                C                                                                MAIN 960
                C                                                                MAIN 970
  ISN 0055         10 CONTINUE                                                   MAIN 980
  ISN 0056            GO TO 1000                                                 MAIN 990
  ISN 0057        99  STOP                                                       MAIN1000
  ISN 0058             END                                                       MAIN1010

                 *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
SYMBOL   INTERNAL STATEMENT NUMBERS
A        0007  0035  0038  0042
I        0019  0025  0027  0027  0027  0031  0031  0031  0033  0033  0033  0052  0052  0052  0052  0052
K        0006
Z        0007  0035  0038  0042
AL       0006  0048
C1       0007  0038  0039
```

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*LEVEL 2.3.0 (JUNE 78)            MAIN           OS/360   FORTRAN H EXTENDED            DATE 82.354/10.15.06        PAGE    3

                              *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
SYMBOL   INTERNAL STATEMENT NUMBERS
C2       0007  0039
LX       0046  0047
RI       0003  0025  0027  0045
R1       0020  0021  0025
R2       0020  0023  0025
SP       0005  0031  0033  0047
LRI      0044  0045
NCO      0049  0052
NRI      0015  0016  0017  0019  0027  0027  0044
NSP      0030  0031  0033  0033  0046
OUT      0006  0013  0014
DABS     0021  0023
ELEC     0004  0049  0052
EMAG     0004  0049  0052
ONCE     0010  0012  0037
PHIM     0011  0036
QABS     0049  0050
QEXT     0049  0050
QSCA     0049  0050
TMAX     0007  0035  0042
TMIN     0007  0035  0039  0042
WAVE     0006  0035  0042
AIRIN    0008
ALPHA    0009  0047  0046  0050
ZMINT    0054
DCMPLX   0025
INDICE   0003  0008  0045  0050
MIEMAN   0049

                              *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
 LABEL    DEFINED     REFERENCES
     1    0028        0015  0027
     2    0029
     3    0032        0033
     5    0043        0042
     7    0051        0050
     8    0053        0052
     9    0041        0040
    10    0055        0044  0046
    20    0026        0019
    99    0057        0016  0C17  0021  0023  0030  0035
  1000    0034        0056

                                                    /    MAIN /     SIZE OF PROGRAM 00845E HEXADECIMAL BYTES

     NAME    TAG   TYPE  ADD.        NAME    TAG   TYPE  ADD.        NAME    TAG   TYPE  ADD.        NAME    TAG   TYPE  ADD.
        A SF   C   R*8   000010         I SF       I*4   000190         K      C   I*4    NR            Z SF   C   R*8   000018
       AL S    C   R*8   000000        C1 SF   C   R*8   000020        C2 S    C   R*8   000028       LX SF       I*4   000194
       RI SF       C*16  000278        R1 SFA      R*8   0001A8        R2 SFA      R*8   0001B0       SP SF       R*8   0001D0
      LRI SF       I*4   000198       NCO SFA      I*4   00019C       NRI SF       I*4   0001A0      NSP SF       I*4   0001A4
      OUT S    C   L*4   000014      ELEC SFA      C*16  0002C8      EMAG SFA      C*16  004148     ONCE S    C   L*4   000000
     PHIM S    C   R*8   000000      QABS SFA      R*8   0001B8      QEXT SFA      R*8   0001C0     QSCA SFA      R*8   0001C8
     TMAX SF   C   R*8   000008      TMIN SF   C   R*8   000000      WAVE SF   C   R*8   000008    AIRIN      C   R*8    NR
```

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*LEVEL 2.3.0 (JUNE 78)          MAIN          OS/360  FORTRAN H EXTENDED          DATE 82.354/10.15.06       PAGE   4

      ALPHA SF    C    R*8    000000     ZMINT SF   XF          000000    IBCOM#     XF    L*4   000000    INDICE SF    C    C*16  000008
     LDFIO#  F   XF    I*4    000000    MIEMAN SF   XF          000000

                                              *****  COMMON INFORMATION   *****

         NAME OF COMMON BLOCK  * INPUT*   SIZE OF BLOCK    000018 HEXADECIMAL BYTES

       VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.
              AL  R*8    000000            WAVE  R*8    000008               K  I*4    000010 NR          OUT  L*4    000014

         NAME OF COMMON BLOCK  *LIMITS*   SIZE OF BLOCK    000030 HEXADECIMAL BYTES

       VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.
            TMIN  R*8    000000            TMAX  R*8    000008               A  R*8    000010               Z  R*8    000018
              C1  R*8    000020              C2  R*8    000028

         NAME OF COMMON BLOCK  *  COM4*   SIZE OF BLOCK    000018 HEXADECIMAL BYTES

       VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.
           AIRIN  R*8    000000 NR       INDICE  C*16   000008

         NAME OF COMMON BLOCK  *  COM5*   SIZE OF BLOCK    000008 HEXADECIMAL BYTES

       VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.
           ALPHA  R*8    000000

         NAME OF COMMON BLOCK  *LOGCOM*   SIZE OF BLOCK    000004 HEXADECIMAL BYTES

       VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.
            ONCE  L*4    000000

         NAME OF COMMON BLOCK  *  DIAG*   SIZE OF BLOCK    000008 HEXADECIMAL BYTES

       VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.
            PHIM  R*8    000000

  SOURCE STATEMENT LABELS

    LABEL  ISN   ADDR            LABEL  ISN   ADDR            LABEL  ISN   ADDR            LABEL  ISN   ADDR
       20   26  008134            1000   34  008220              10   55  0083FA              99   57  00842C

  COMPILER GENERATED LABELS

    LABEL  ISN   ADDR            LABEL  ISN   ADDR            LABEL  ISN   ADDR            LABEL  ISN   ADDR
   100000    1  008064          100001   16  00808C          100002   16  0080A0          100003   19  0080BA
   100004   20  0080C2          100005   23  0080F8          100006   25  008108          100007   27  00814A
   100010   30  008184          100011   30  008198          100012   31  0081BC          100013   31  0081E2
   100016   35  008220          100017   35  008234          100018   45  0082F4          100019   47  008318
   100020   52  0083A0          100021   52  0083EA          100022   56  008410          100023   56  008426

  FORMAT STATEMENT LABELS
```

```
  LABEL  ISN   ADDR          LABEL  ISN   ADDR          LABEL  ISN   ADDR          LABEL  ISN   ADDR
      1   28  000028             2   29  000036 NR          3   32  000040             9   41  00004D
      5   43  000080             7   51  00008C             8   53  0000F2

*OPTIONS IN EFFECT*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

*OPTIONS IN EFFECT*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

*STATISTICS*    SOURCE STATEMENTS =      57, PROGRAM SIZE =     33886, SUBPROGRAM NAME =  MAIN

*STATISTICS*  NO  DIAGNOSTICS GENERATED

****** END OF COMPILATION ******                                      104K BYTES OF CORE NOT USED
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*LEVEL 2.3.0 (JUNE 78)                  OS/360  FORTRAN H EXTENDED             DATE 82.354/10.15.06        PAGE   1

REQUESTED OPTIONS: XREF,MAP,OPT=0,GOSTMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
                   SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

  ISN 0002             SUBROUTINE MIEMAN(QEXT, QSCAT, QABS, ELEC, EMAG, LL)            MIEM  10
                 C                                                                       MIEM  20
                 C                                                                       MIEM  30
  ISN 0003             IMPLICIT REAL*8(A-Z)                                              MIEM  40
  ISN 0004             COMPLEX*16 EPERI,EPER,EHOZI,EHOZ,ELEC(1000),EMAG(1000),BB,DD,BETA MIEM  50
                      1,INDICE                                                           MIEM  60
                 C                                                                       MIEM  70
  ISN 0005             COMMON/COM1/B(1001)/COM2/NE(1001)/COM3/BETA/COM4/AIRIN,INDICE/    MIEM  80
                      1COM5/ALPHA                                                        MIEM  90
  ISN 0006             COMMON/COM7/ X1,X2,Y1,Y2,XX                                       MIEM 100
                 C                                                                       MIEM 110
                 C                                                                       MIEM 120
  ISN 0007             INTEGER J,L,N,IA,IB,JI,JJ,LL,IJKL                                 MIEM 130
  ISN 0008             DIMENSION PO(1000),PA(1000)                                       MIEM 140
  ISN 0009             DIMENSION W(2)                                                    MIEM 150
                 C                                                                       MIEM 160
                 C                                                                       MIEM 170
  ISN 0010             AIRIN=1.0D0                                                       MIEM 180
                 C                                                                       MIEM 190
                 C                                                                       MIEM 200
  ISN 0011             DO 8521  IJKL=1,1000                                              MIEM 210
  ISN 0012             B(IJKL)=0.0D+00                                                   MIEM 220
  ISN 0013             NE(IJKL)=0.0D+00                                                  MIEM 230
  ISN 0014             ELEC(IJKL)=(0.0D+00,0.0D+00)                                      MIEM 240
  ISN 0015             EMAG(IJKL)=(0.0D+00,0.0D+00)                                      MIEM 250
  ISN 0016       8521  CONTINUE                                                          MIEM 260
                 C                                                                       MIEM 270
                 C                                                                       MIEM 280
                 C     PI=4*DATAN(1.0D0)                                                 MIEM 290
  ISN 0017             BETA=INDICE*ALPHA/AIRIN                                           MIEM 300
  ISN 0018             L=IFIX(SNGL(ALPHA))                                               MIEM 310
  ISN 0019             J=2*L                                                             MIEM 320
  ISN 0020             IF(J.GT.15) GO TO 1234                                            MIEM 330
                 C                                                                       MIEM 340
                 C                                                                       MIEM 350
                 C           CALL FOR SUBROUTINES VIBRA,BESSEL,NEUMAN.                   MIEM 360
                 C                                                                       MIEM 370
                 C    VIBRA,BESSEL,NEUMAN ARE SUPERMIDI ROUTINES.                        MIEM 380
                 C                                                                       MIEM 390
                 C                                                                       MIEM 400
  ISN 0022             J=15                                                              MIEM 410
  ISN 0023       1234  JJ=J+1                                                            MIEM 420
                 C                                                                       MIEM 430
  ISN 0024             CALL BESSEL(JJ,B,IA)                                              MIEM 440
  ISN 0025             JJ=IA                                                             MIEM 450
                 C                                                                       MIEM 460
  ISN 0026             CALL NEUMAN(JJ,NE,IB)                                             MIEM 470
                 C                                                                       MIEM 480
  ISN 0027             J=IB-1                                                            MIEM 490
                 C                                                                       MIEM 500
  ISN 0028             CALL VIBRA(ELEC,EMAG,J,LL)                                        MIEM 510
                 C                                                                       MIEM 520
  ISN 0029       37    QSCAT=0.0D0                                                       MIEM 530
```

```
ISN 0030             QEXT=0.0D0                                              MIEM 540
ISN 0031             DO 59 N=1,LL                                            MIEM 550
ISN 0032             RA=DREAL(ELEC(N))                                       MIEM 560
ISN 0033             RB=DREAL(EMAG(N))                                       MIEM 570
ISN 0034             CA=ELEC(N)*DCONJG(ELEC(N))                              MIEM 580
ISN 0035             CB=EMAG(N)*DCONJG(EMAG(N))                              MIEM 590
ISN 0036             RCOEF=2.0D0*N+1.0D0                                     MIEM 600
ISN 0037             QSCAT=QSCAT+RCOEF*(CA+CB)                               MIEM 610
ISN 0038             QEXT=QEXT+RCOEF*(RA+RB)                                 MIEM 620
ISN 0039          59 CONTINUE                                                MIEM 630
ISN 0040             RCO = 2.0D0/(ALPHA**2)                                  MIEM 640
ISN 0041             QEXT = QEXT*RCO                                         MIEM 650
ISN 0042             QSCAT = RCO*QSCAT                                       MIEM 660
ISN 0043             QABS = QEXT-QSCAT                                       MIEM 670
                C                                                            MIEM 680
                C                                                            MIEM 690
ISN 0044             RETURN                                                  MIEM 700
                C                                                            MIEM 710
                C    W(1) IS THETA   AND W(2) IS PHI                         MIEM 720
ISN 0045             ENTRY MIECXU(W,EPER,EHOZ,DELT)                          MIEM 730
                C  MIECXU IS A SUPERMIDI ROUTINE.                            MIEM 740
                C                                                            MIEM 750
ISN 0046             TETA = W(1)                                             MIEM 760
                C                                                            MIEM 770
                C                                                            MIEM 780
                C                                                            MIEM 790
ISN 0047             EPER1=(0.0D0,0.0D0)                                     MIEM 800
ISN 0048             EHOZ1=(0.0D0,0.0D0)                                     MIEM 810
                C                                                            MIEM 820
                C                                                            MIEM 830
ISN 0049             CALL POLY(J,PO,PA,TETA)                                 MIEM 840
                C                                                            MIEM 850
                C  POLY IS A SUPERMIDI ROUTINE.                              MIEM 860
                C                                                            MIEM 870
                C                                                            MIEM 880
ISN 0050             DO 5 N=1,LL                                             MIEM 890
ISN 0051             X=N                                                     MIEM 900
ISN 0052             EPER=EPER1                                              MIEM 910
ISN 0053             EHOZ=EHOZ1                                              MIEM 920
ISN 0054             CC=PO(N)                                                MIEM 930
ISN 0055             EE=PA(N)                                                MIEM 940
ISN 0056             BB=ELEC(N)                                              MIEM 950
ISN 0057             DD=EMAG(N)                                              MIEM 960
ISN 0058             HH=(2.0D0*X+1.0D0)/(X*(X+1.0D0))                        MIEM 970
ISN 0059             EPER1=EPER+HH*(BB*CC+DD*EE)                             MIEM 980
ISN 0060             EHOZ1=EHOZ+HH*(BB*EE+DD*CC)                             MIEM 990
                C                                                            MIEM1000
ISN 0061        5    CONTINUE                                                MIEM1010
                C                                                            MIEM1020
                C                                                            MIEM1030
ISN 0062             X1=DREAL(EPER1)                                         MIEM1040
ISN 0063             X2=DREAL(EHOZ1)                                         MIEM1050
ISN 0064             Y1=DIMAG(EPER1)                                         MIEM1060
ISN 0065             Y2=DIMAG(EHOZ1)                                         MIEM1070
ISN 0066             XX=(X1*Y2-X2*Y1)/(X1*X2+Y1*Y2)                          MIEM1080
ISN 0067             DELT=DATAN(XX)                                          MIEM1090
                                                                             MIEM1100
                   DELT IS THE PHASE DIFFERENCE BETWEEN THE PERPINDICULAR AND
```

```
                C     PARALLEL COMPONENTS OF THE ELLIPTICALLY POLARIZED SCAT.LIGHT (RADS)
                C                                                                     MIEM1120
                C                                                                     MIEM1130
   ISN 0068              RETURN                                                       MIEM1140
                C                                                                     MIEM1150
   ISN 0069              END                                                          MIEM1160

                        *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
SYMBOL  INTERNAL STATEMENT NUMBERS
B       0005 0012 0024
J       0007 0019 0020 0022 0023 0027 0028 0049
L       0007 0018 0019
N       0007 0031 0032 0033 0034 0034 0035 0035 0036 0050 0051 0054 0055 0056 0057
W       0009 0045 0046
X       0051 0058 0058 0058
BB      0004 0056 0059 0060
CA      0034 0037
CB      0035 0037
CC      0054 0059 0060
DD      0004 0057 0059 0060
FE      0055 0059 0060
HH      0058 0059 0060
IA      0007 0024 0025
IB      0007 0026 0027
JI      0007
JJ      0007 0023 0024 0025 0026
LL      0002 0007 0028 0031 0050
NE      0005 0013 0026
PA      0008 0049 0055
PO      0008 0049 0054
RA      0032 0038
RB      0033 0038
XX      0006 0066 0067
X1      0006 0062 0066 0066
X2      0006 0063 0066 0066
Y1      0006 0064 0066 0066
Y2      0006 0065 0066 0066
RCO     0040 0041 0042
BETA    0004 0005 0017
DELT    0045 0067
EHOZ    0004 0045 0053 0060
ELEC    0002 0004 0014 0028 0032 0034 0034 0056
EMAG    0002 0004 0015 0028 0033 0035 0035 0057
EPER    0004 0045 0052 0059
IFIX    0018
IJKL    0007 0011 0012 0013 0014 0015
POLY    0049
QABS    0002 0043
QEXT    0002 0030 0038 0038 0041 0041 0043
SNGL    0018
TETA    0046 0049
AIRIN   0005 0010 0017
ALPHA   0005 0017 0018 0040
DATAN   0067
DIMAG   0064 0065
DREAL   0032 0033 0062 0063
EHOZ1   0004 0048 0053 0060 0063 0065
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                    *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
SYMBOL   INTERNAL STATEMENT NUMBERS
EPERI    0004  0047  0052  0059  0062  0064
QSCAT    0002  0029  0037  0037  0042  0042  0043
RCOEF    0036  0037  0038
VIBRA    0028
BESSEL   0024
DCONJG   0034  0035
INDICE   0004  0005  0017
MIECXU   0045
MIEMAN   0002
NEUMAN   0026

                    *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
 LABEL   DEFINED    REFERENCES
    5    0061       0050
   37    0029
   59    0039       0031
 1234    0023       0020
 8521    0016       0011

                                                  /   MIEMAN /     SIZE OF PROGRAM 0048F8 HEXADECIMAL BYTES

   NAME     TAG    TYPE   ADD.        NAME     TAG    TYPE   ADD.        NAME     TAG    TYPE   ADD.        NAME     TAG    TYPE   ADD.
      B SFA  C     R*8    000000         J SFA        I*4    000160         L SF          I*4    000164         N SFA         I*4    000168
      W  F   XR    R*8    000000         X SF         R*8    000180        BB SF          C*16   000210        CA SF          R*8    000188
     CB SF         R*8    000190        CC SF         R*8    000198        DD SF          C*16   000220        EE SF          R*8    0001A0
     HH SF         R*8    0001A8        IA SFA        I*4    00016C        IB SFA         I*4    000170        JI             I*4    NR
     JJ SFA        I*4    000174        LL SFA        I*4    000178        NE SFA  C      R*8    000000        PA SFA         R*8    000270
     PO SFA        R*8    0021B0        RA SF         R*8    000180        RB SF          R*8    0001B8        XX SFA  C      R*8    000020
     X1 SF   C     R*8    000000        X2 SF   C     R*8    000008        Y1 SF   C      R*8    000010        Y2 SF   C      R*8    000018
    RCO SF         R*8    0001C0      BETA S    C     C*16   000000      DELT S           R*8    0001C8      EHOZ SF          C*16   000230
   ELEC SFA XR     C*16   000000      EMAG SFA XR     C*16   000000      EPER SF          C*16   000240      IJKL SF          I*4    00017C
   POLY SF  XF            000000      QABS S          R*8    000100      QEXT SF          R*8    0001D8      TETA SFA         R*8    0001E0
  AIRIN SF   C     R*8    000000     ALPHA  FA  C     R*8    000000     DATAN  F  XF      R*8    000000     EHOZ1 SFA         C*16   000250
  EPERI SFA        C*16   000260     QSCAT SF         R*8    0001E8     RCOEF SF          R*8    0001F0     VIBRA SF  XF            000000
 CDDVD#     XF     C*16   000000    CDMPY#     XF     C*16   000000    BESSEL SF  XF             000000    INDICE  F   C     C*16   000008
 MIECXU            R*8    0001F8    MIEMAN            R*8    000200    NEUMAN SF  XF             000000
                                       *****  COMMON INFORMATION   *****

     NAME OF COMMON BLOCK  *  COM1*   SIZE OF BLOCK    001F48 HEXADECIMAL BYTES

    VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
           B   R*8    000000

     NAME OF COMMON BLOCK  *  COM2*   SIZE OF BLOCK    001F48 HEXADECIMAL BYTES

    VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
          NE   R*8    000000

     NAME OF COMMON BLOCK  *  COM3*   SIZE OF BLOCK    000010 HEXADECIMAL BYTES
```

```
     VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
         BETA   C*16   000000

      NAME OF COMMON BLOCK  *  COM4*   SIZE OF BLOCK    000018 HEXADECIMAL BYTES

     VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
        AIRIN   R*8    000000         INDICE  C*16   000008

      NAME OF COMMON BLOCK  *  COM5*   SIZE OF BLOCK    000008 HEXADECIMAL BYTES

     VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
        ALPHA   R*8    000000

      NAME OF COMMON BLOCK  *  COM7*   SIZE OF BLOCK    000028 HEXADECIMAL BYTES

     VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
           X1   R*8    000000             X2  R*8    000008             Y1  R*8    000010             Y2  R*8    000018
           XX   R*8    000020

  SOURCE STATEMENT LABELS

    LABEL  ISN  ADDR          LABEL  ISN  ADDR          LABEL  ISN  ADDR          LABEL  ISN  ADDR
     8521   16  00421C         1234   23  004206           37   29  004320 NR        59   39  004474
        5   61  004706

  COMPILER GENERATED LABELS

    LABEL  ISN  ADDR          LABEL  ISN  ADDR          LABEL  ISN  ADDR          LABEL  ISN  ADDR
   100001    2  0041A8       100002   12  0041BC       100003   17  004232       100004   22  0042CE
   100005   32  004334       100006   40  00448A       100007   45  000000       100008   45  0044CC
   100009   51  00450E       100010   62  00471C

*OPTIONS IN EFFECT*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

*OPTIONS IN EFFECT*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

*STATISTICS*     SOURCE STATEMENTS =      68, PROGRAM SIZE =     18680, SUBPROGRAM NAME =MIEMAN

*STATISTICS*  NO  DIAGNOSTICS GENERATED

****** END OF COMPILATION ******                                   96K BYTES OF CORE NOT USED
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*LEVEL 2.3.0 (JUNE 78)                    OS/360  FORTRAN H EXTENDED            DATE 82.354/10.15.07        PAGE   1

REQUESTED OPTIONS: XREF,MAP,OPT=0,GOSTMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
                   SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

    ISN 0002              SUBROUTINE ZMINT                                                        ZMIN  10
                    C                                                                             ZMIN  20
    ISN 0003              IMPLICIT REAL*8(A-H,O-Z)                                                ZMIN  30
    ISN 0004              DIMENSION I(2),ZZ(2)                                                    ZMIN  40
    ISN 0005              COMMON/INPUT/AL,WAVE,K,OUT                                              ZMIN  50
    ISN 0006              EXTERNAL XLOW,XUPP,FUNEV                                                ZMIN  60
    ISN 0007              LOGICAL OUT                                                             ZMIN  70
    ISN 0008              I(1)=1                                                                  ZMIN  80
    ISN 0009              I(2)=1                                                                  ZMIN  90
    ISN 0010              CC=1.0141358D-10                                                        ZMIN 100
    ISN 0011              DO 33 K=1,2                                                             ZMIN 110
    ISN 0012              O4T=.FALSE.                                                             ZMIN 120
                    C                                                                             ZMIN 130
    ISN 0013              Z=XMINT(3,2,I,XLOW,XUPP,FUNEV)                                          ZMIN 140
                    C                                                                             ZMIN 150
                    C     INCIDENT POWER IS THE ACTUAL LASER POWER.THE FACTOR OF 2 RESULTING ZMIN 1W
                    C     FROM THE BEAM SPLITTING IS ACCOUNTED FOR IN THE INTEGRATION OVER   ZMIN 1X
                    C     ONLY ONE-HALF THE APERTURE.                                             ZMIN 180
    ISN 0014              ZZ(K)=CC*Z                                                              ZMIN 190
                    C                                                                             ZMIN 200
    ISN 0015           33 CONTINUE                                                                ZMIN 210
    ISN 0016              V=(ZZ(1)-ZZ(2))/(ZZ(1)+ZZ(2))                                           ZMIN 220
    ISN 0017              PM=(ZZ(1)+ZZ(2))/2                                                      ZMIN 230
                    C                                                                             ZMIN 240
    ISN 0018              PRINT 1,ZZ(1),ZZ(2),PM                                                  ZMIN 250
    ISN 0019            1 FORMAT('0 COLLECTED POWER (P/I),MAX='     1PG14.6,                     ZMIN 260
                         1' MIN= ',    1PG14.6      ,'      MEAN='     1PG14.6         )          ZMIN 270
    ISN 0020              PRINT 3,V                                                               ZMIN 280
    ISN 0021            3 FORMAT('0 VISIBILITY=',      1PG20.8)                                   ZMIN 290
    ISN 0022              RETURN                                                                  ZMIN 300
    ISN 0023              END                                                                     ZMIN 310

                          *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
SYMBOL   INTERNAL STATEMENT NUMBERS
I        0004  0008  0009  0013
K        0005  0011  0014
V        0016  0020
Z        0013  0014
AL       0005
CC       0010  0014
PM       0017  0018
ZZ       0004  0014  0016  0016  0016  0016  0017  0017  0018  0018
OUT      0005  0007
O4T      0012
WAVE     0005
XLOW     0006  0013
XUPP     0006  0013
FUNEV    0006  0013
XMINT    0013
ZMINT    0002
```

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*LEVEL 2.3.0 (JUNE 78)          ZMINT          OS/360  FORTRAN H EXTENDED          DATE 82.354/10.15.07        PAGE   2
                         *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
 LABEL   DEFINED   REFERENCES
   1      0019      0018
   3      0021      0020
  33      0015      0011

                                                   /  ZMINT /    SIZE OF PROGRAM 0002C4 HEXADECIMAL BYTES

    NAME    TAG    TYPE  ADD.        NAME    TAG   TYPE  ADD.        NAME    TAG   TYPE  ADD.        NAME    TAG    TYPE  ADD.
      I SFA        I*4   000140        K SF   C    I*4   000010        V SF        R*8   000110        Z SF         R*8   000118
     AL       C    R*8     NR         CC SF        R*8   000120       PM SF        R*8   000128       ZZ SF         R*8   000148
    OUT       C    L*4   000014      OUT S         R*8   000130     WAVE      C    R*8     NR       XLOW   A XF    R*8   000000
   XUPP    A XF    R*8   000000    FUNEV   A XF    R*8   000000    XMINT  F  XF    R*8   000000    ZMINT          R*8   000138
 IBCOM#      XF    I*4   000000
                                        *****  COMMON INFORMATION  *****

     NAME OF COMMON BLOCK  * INPUT*   SIZE OF BLOCK    000018 HEXADECIMAL BYTES

   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
         AL   R*8   000000 NR         WAVE  R*8   000008 NR            K  I*4   000010             OUT  L*4   000014


 SOURCE STATEMENT LABELS

   LABEL  ISN  ADDR          LABEL  ISN  ADDR          LABEL  ISN  ADDR          LABEL  ISN  ADDR
     33    15  0001F6

 COMPILER GENERATED LABELS

   LABEL  ISN  ADDR          LABEL  ISN  ADDR          LABEL  ISN  ADDR          LABEL  ISN  ADDR
  100001    2  000190       100002   12  0001B4       100003   16  000210

 FORMAT STATEMENT LABELS

   LABEL  ISN  ADDR          LABEL  ISN  ADDR          LABEL  ISN  ADDR          LABEL  ISN  ADDR
      1    19  000028            3   21  00006A

*OPTIONS IN EFFECT*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

*OPTIONS IN EFFECT*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

*STATISTICS*    SOURCE STATEMENTS =      22, PROGRAM SIZE =      708, SUBPROGRAM NAME = ZMINT

*STATISTICS*  NO  DIAGNOSTICS GENERATED

****** END OF COMPILATION ******                                        108K BYTES OF CORE NOT USED
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*LEVEL 2.3.0 (JUNE 78)                    OS/360  FORTRAN H EXTENDED          DATE 82.354/10.15.07        PAGE    1

REQUESTED OPTIONS: XREF,MAP,OPT=0,GOSTMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
                   SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

   ISN 0002          FUNCTION XLOW (J, X)                                                     FUNC  10
   ISN 0003          IMPLICIT REAL*8(A-H,O-Z)                                                 FUNC  20
   ISN 0004          COMMON/LIMITS/ TMIN,TMAX,A,Z,C1,C2                                       FUNC  30
   ISN 0005          XLOW=0.0D0                                                               FUNC  40
   ISN 0006          IF(J.EQ.1) XLOW=TMIN                                                     FUNC  50
   ISN 0008          IF(TMIN .LT.  0.0D0 ) XLOW=0.0D0                                         FUNC  60
   ISN 0010          RETURN                                                                   FUNC  70
   ISN 0011          END                                                                      FUNC  80

                  *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
SYMBOL  INTERNAL STATEMENT NUMBERS
A       0004
J       0002  0006
X       0002
Z       0004
C1      0004
C2      0004
TMAX    0004
TMIN    0004  0006  0008
XLOW    0002  0005  0006  0008

                                               /     XLOW /     SIZE OF PROGRAM 00012A HEXADECIMAL BYTES

      NAME     TAG   TYPE  ADD.        NAME    TAG   TYPE  ADD.       NAME    TAG   TYPE  ADD.       NAME    TAG   TYPE  ADD.
        A       C    R*8     NR          J           I*4   000084       X           R*8   000088       Z       C    R*8    NR
       C1       C    R*8     NR         C2      C    R*8     NR       TMAX     C    R*8     NR      TMIN  F   C    R*8  000000
      XLOW S         R*8   000090
                                      *****  COMMON INFORMATION   *****

        NAME OF COMMON BLOCK  *LIMITS*   SIZE OF BLOCK    000030 HEXADECIMAL BYTES

      VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.
          TMIN   R*8    000000            TMAX   R*8    000008 NR          A    R*8    000010 NR          Z    R*8    000018 NR
            C1   R*8    000020 NR           C2   R*8    000028 NR


  COMPILER GENERATED LABELS

    LABEL   ISN   ADDR          LABEL   ISN   ADDR          LABEL   ISN   ADDR          LABEL   ISN   ADDR
   100001     2  0000B8        100002     7  0000CE        100003     8  0000DA        100004     9  0000EA
   100005    10  0000F2

*OPTIONS IN EFFECT*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

*OPTIONS IN EFFECT*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

*STATISTICS*     SOURCE STATEMENTS =      10, PROGRAM SIZE =      298, SUBPROGRAM NAME =  XLOW

*STATISTICS*  NO  DIAGNOSTICS GENERATED
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****** END OF COMPILATION ******                    108K BYTES OF CORE NOT USED
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*LEVEL 2.3.0 (JUNE 78)                 OS/360   FORTRAN H EXTENDED          DATE 82.354/10.15.07        PAGE   1

REQUESTED OPTIONS: XREF,MAP,OPT=0,GOSTMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
                   SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

      ISN 0002           FUNCTION XUPP (J, X)                                                    FUNC  10
      ISN 0003           IMPLICIT REAL*8(A-H,O-Z)                                                FUNC  20
      ISN 0004               DIMENSION  X(2)                                                     FUNC  30
      ISN 0005           COMMON/LOGCOM/ONCE                                                      FUNC  40
      ISN 0006           COMMON/LIMITS/ TMIN,TMAX,A,Z,C1,C2                                      FUNC  50
      ISN 0007           LOGICAL ONCE                                                            FUNC  60
      ISN 0008           GO TO(1,2),J                                                            FUNC  70
      ISN 0009      1    XUPP=TMAX                                                               FUNC  80
      ISN 0010           RETURN                                                                  FUNC  90
      ISN 0011         2 XUPP=0.0D0                                                              FUNC 100
      ISN 0012           IF ( TMIN .LT. 0.0D0 ) GOTO 30                                          FUNC 110
      ISN 0014           IF (X(1).EQ.0.0) RETURN                                                 FUNC 120
      ISN 0016           XN=DCOS(C1)-DCOS(X(1))*DCOS(C2)                                         FUNC 130
      ISN 0017           XD=DSIN(X(1))*DSIN(C2)                                                  FUNC 140
      ISN 0018           XUPP=DARCOS(XN/XD)                                                      FUNC 150
      ISN 0019           GOTO 40                                                                 FUNC 160
      ISN 0020        30 XUPP=3.14159D0                                                          FUNC 170
      ISN 0021        40 CONTINUE                                                                FUNC 180
      ISN 0022           IF (ONCE) GOTO110                                                       FUNC 190
      ISN 0024           ONCE=.TRUE.                                                             FUNC 200
      ISN 0025           PRINT4,X(1),XUPP                                                        FUNC 210
      ISN 0026         4 FORMAT(' XUPP=',1PG20.8)                                                FUNC 220
      ISN 0027       110 CONTINUE                                                                FUNC 230
      ISN 0028           RETURN                                                                  FUNC 240
      ISN 0029           END                                                                     FUNC 250

                 *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
SYMBOL   INTERNAL STATEMENT NUMBERS
A        0006
J        0002  0008
X        0002  0004  0014  0016  0017  0025
Z        0006
C1       0006  0016
C2       0006  0016  0017
XD       0017  0018
XN       0016  0018
DCOS     0016  0016  0016
DSIN     0017  0017
ONCE     0005  0007  0022  0024
TMAX     0006  0009
TMIN     0006  0012
XUPP     0002  0009  0011  0018  0020  0025
DARCOS   0018

                 *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
 LABEL    DEFINED     REFERENCES
     1    0009        0008
     2    0011        0008
     4    0026        0025
    30    0020        0012
    40    0021        0019
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*LEVEL 2.3.0 (JUNE 78)          XUPP          OS/360  FORTRAN H EXTENDED            DATE 82.354/10.15.07        PAGE    2

                         *****F O R T R A N    C R O S S    R E F E R E N C E    L I S T I N G*****
 LABEL    DEFINED    REFERENCES
  110     0027       0022

                                                        /     XUPP /     SIZE OF PROGRAM 0002F2 HEXADECIMAL BYTES

     NAME     TAG    TYPE   ADD.         NAME     TAG    TYPE   ADD.         NAME     TAG    TYPE   ADD.         NAME     TAG    TYPE   ADD.
        A       C    R*8      NR            J   F        I*4    0000BC          X   FA XR    R*8    000000          Z       C    R*8      NR
       C1   FA  C    R*8    000020         C2   FA  C    R*8    000028         XD  SFA       R*8    0000C0         XN  SFA       R*8    0000C8
     DCOS   F  XF    R*8    000000       DSIN   F  XF    R*8    000000       ONCE  S     C   L*4    000000       TMAX   F   C    R*8    000008
     TMIN       C    R*8    000000       XUPP SF         R*8    0000D0     DARCOS   F  XF    R*8    000000     IBCOM#      XF    L*4    000000

                                         *****  COMMON INFORMATION   *****

      NAME OF COMMON BLOCK  *LOGCOM*   SIZE OF BLOCK    000004 HEXADECIMAL BYTES

     VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
         ONCE   L*4    000000

      NAME OF COMMON BLOCK  *LIMITS*   SIZE OF BLOCK    000030 HEXADECIMAL BYTES

     VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
         TMIN   R*8    000000          TMAX   R*8    000008             A   R*8    000010 NR           Z   R*8    000018 NR
           C1   R*8    000020            C2   R*8    000028


  SOURCE STATEMENT LABELS

    LABEL   ISN   ADDR             LABEL   ISN   ADDR             LABEL   ISN   ADDR             LABEL   ISN   ADDR
        1     9   00015A               2    11   00016E              30    20   00025E              40    21   000266
      110    27   0002AC

  COMPILER GENERATED LABELS

    LABEL   ISN   ADDR             LABEL   ISN   ADDR             LABEL   ISN   ADDR             LABEL   ISN   ADDR
   100001     2   000140          100003    14   000186          100004    15   000196          100005    16   00019E
   100006    24   000278

  FORMAT STATEMENT LABELS

    LABEL   ISN   ADDR             LABEL   ISN   ADDR             LABEL   ISN   ADDR             LABEL   ISN   ADDR
        4    26   000028

*OPTIONS IN EFFECT*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

*OPTIONS IN EFFECT*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

*STATISTICS*     SOURCE STATEMENTS =      28, PROGRAM SIZE =      754, SUBPROGRAM NAME =  XUPP

*STATISTICS*  NO  DIAGNOSTICS GENERATED

****** END OF COMPILATION ******                                  108K BYTES OF CORE NOT USED
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*LEVEL 2.3.0 (JUNE 78)                    OS/360   FORTRAN H EXTENDED          DATE 82.354/10.15.07       PAGE    1

REQUESTED OPTIONS: XREF,MAP,OPT=0,GOSTMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
                   SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

   ISN 0002              FUNCTION FUNEV(J,X)                                                      FUNC  10
   ISN 0003              IMPLICIT REAL*8(A-H,O-Z)                                                 FUNC  20
   ISN 0004              COMMON/INPUT/AL,WAVE,K                                                   FUNC  30
   ISN 0005              DIMENSION X(2),E(2),W(2)                                                 FUNC  40
   ISN 0006              GO TO (1,2),J                                                            FUNC  50
   ISN 0007          1   FUNEV=1.0D0                                                              FUNC  60
   ISN 0008              RETURN                                                                   FUNC  70
   ISN 0009           2  CONTINUE                                                                 FUNC  80
                    C                                                                             FUNC  90
   ISN 0010              CALL BESEL3 (X,W)                                                        FUNC 100
   ISN 0011              FUNEV=W(K)*DSIN(X(1))                                                    FUNC 110
   ISN 0012              RETURN                                                                   FUNC 120
   ISN 0013              END                                                                      FUNC 130

                        *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
SYMBOL   INTERNAL STATEMENT NUMBERS
E        0005
J        0002  0006
K        0004  0011
W        0005  0010  0011
X        0002  0005  0010  0011
AL       0004
DSIN     0011
WAVE     0004
FUNEV    0002  0007  0011
BESEL3   0010

                        *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
 LABEL    DEFINED    REFERENCES
    1     0007       0006
    2     0009       0006

                                                 /   FUNEV /    SIZE OF PROGRAM 0001BC HEXADECIMAL BYTES

     NAME    TAG    TYPE  ADD.        NAME    TAG   TYPE  ADD.        NAME    TAG   TYPE  ADD.       NAME    TAG    TYPE  ADD.
        E           R*8    NR            J  F       I*4   00009C        K  F  C     I*4   000010       W SFA        R*8   0000A8
        X SFA XR    R*8   000000        AL      C   R*8    NR        DSIN  F  XF    R*8   000000    WAVE       C    R*8    NR
    FUNEV S         R*8   0000A0    BESEL3 SF XF          000000
                                          *****  COMMON INFORMATION   *****

      NAME OF COMMON BLOCK  * INPUT*   SIZE OF BLOCK    000014 HEXADECIMAL BYTES

     VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
           AL   R*8   000000 NR         WAVE  R*8   000008 NR            K  I*4   000010


  SOURCE STATEMENT LABELS
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*LEVEL 2.3.0 (JUNE 78)                    OS/360  FORTRAN H EXTENDED          DATE 82.354/10.15.07       PAGE   2

    LABEL   ISN   ADDR           LABEL   ISN   ADDR           LABEL   ISN   ADDR           LABEL   ISN   ADDR
        1     7  000112              2     9  000122

  COMPILER GENERATED LABELS

    LABEL   ISN   ADDR           LABEL   ISN   ADDR           LABEL   ISN   ADDR           LABEL   ISN   ADDR
   100001     2  0000F8

*OPTIONS IN EFFECT*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

*OPTIONS IN EFFECT*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

*STATISTICS*     SOURCE STATEMENTS =       12, PROGRAM SIZE =       444, SUBPROGRAM NAME = FUNEV

*STATISTICS*  NO  DIAGNOSTICS GENERATED

****** END OF COMPILATION ******                                       108K BYTES OF CORE NOT USED
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*LEVEL 2.3.0 (JUNE 78)                    OS/360   FORTRAN H EXTENDED           DATE 82.354/10.15.07        PAGE    1

REQUESTED OPTIONS: XREF,MAP,OPT=0,GOSTMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(6   SIZE(MAX) AUTODBL(NONE)
                   SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

   ISN 0002            SUBROUTINE BESEL3(X,W)                                              BESE  10
                 C                                                                         BESE  20
                 C    THE LDV INPUT BEAM IS POLARIZED PARALLEL TO THE OX AXIS(VERTICAL)   BESE  30
                 C                                                                         BESE  40
                 C    GAMMA IS ONE-HALF THE TOTAL ANGLE OF SEPARATION OF THE TWO LDV BEAMSBESE  50
                 C    FOR GAMMA = 1.03 DEGREES USE CARD 1                                  BESE  60
                 C    CARD 1 REAL*8 GSC(2,2)/.01796900, 0.999838D0, -0.017960D0,0.999838D0BESE  70
                 C    FOR GAMMA = .645 DEGREES USE CARD 2                                  BESE  80
                 C    CARD 2 REAL*8 GSC(2,2)/ 0.011249D0,0.999367D0,-0.011249D0,0.9999367DBESE  90
                 C                                                                         BESE 100
                 C    J-IS THE INDEX FOR THE TWO BEAMS 1-LEFT;2-RIGHT LOOKING TOWARDS THE BESE 110
                 C    K-INDEX USED TO CALCULATE VISIBILITY.FOR K 1,BOTH BEAMS ARE IN PHASEBESE 120
                 C    SCATTERER;FOR K 2,THE PHASE OF BEAM TWO IS SHIFTED 180 DEGREES.     BESE 130
                 C                                                                         BESE 140
   ISN 0003            IMPLICIT REAL*8(A-H,O-Z)                                            BESE 150
   ISN 0004               REAL*8 GSC(2,2)/.01796900, 0.999838D0, -0.017960D0,0.999838D0/  BESE 160
   ISN 0005            COMPLEX*16 E1(2),E2(2),E(2),EPER,EHOZ                               BESE 170
   ISN 0006            COMMON/INPUT/AL,WAVE,K,OUT                                          BESE 180
   ISN 0007            COMMON/PARM/RAD,FN                                                  BESE 190
   ISN 0008            COMMON/DIAG/PHIM                                                    BESE 200
   ISN 0009            COMMON/COM7/ X1,X2,Y1,Y2,XX                                         BESE 210
   ISN 0010            DIMENSION X(2),W(2),ARG(2)                                          BESE 220
   ISN 0011            DIMENSION CSTH(2,2),PSI(2),PHI(2)                                   BESE 230
                 C                                                                         BESE 240
   ISN 0012            LOGICAL ONCE/.FALSE./                                               BESE 250
   ISN 0013            LOGICAL OUT                                                         BESE 260
   ISN 0014            DELT1=0.0D0                                                         BESE 270
   ISN 0015            IF (ONCE) GOTO110                                                   BESE 280
   ISN 0017            ONCE=.TRUE.                                                         BESE 290
                 C                                                                         BESE 300
                 C                                                                         BESE 310
   ISN 0018            PI = 4.0D0 * DATAN( 1.0D0)                                          BESE 320
   ISN 0019            DEG = 180.0 / PI                                                    BESE 330
   ISN 0020            GAM=DARSIN(GSC(1,1))                                                BESE 340
   ISN 0021            SGAM = GSC(1,1)                                                     BESE 350
   ISN 0022            CGAM = DCOS(GAM)                                                    BESE 360
                 C     FN=INTERFERENCE FRINGE IN MICRONS                                   BESE 370
   ISN 0023            FN=((WAVE)/GSC(1,1))/2                                              BESE 380
   ISN 0024        110 CONTINUE                                                            BESE 390
                 C                                                                         BESE 400
   ISN 0025            SX1=DSIN(X(1))                                                      BESE 410
   ISN 0026            CX1=DCOS(X(1))                                                      BESE 420
   ISN 0027            SX2=DSIN(X(2))                                                      BESE 430
   ISN 0028            CX2=DCOS(X(2))                                                      BESE 440
                 C                                                                         BESE 450
   ISN 0029            SGN2=1.0D0                                                          BESE 460
                 C                                                                         BESE 470
   ISN 0030            DO 45 J=1,2                                                         BESE 480
   ISN 0031            SGN=(3-2*J)                                                         BESE 490
   ISN 0032            IF( K.EQ.2 .AND. J. EQ. 2) SGN2=-1.0D0                              BESE 500
                 C     CSTH(K,J)=CX1*DCOS(GAM)+SX1*SX2*DSIN(GAM)*SGN                       BESE 510
   ISN 0034            CSTH(K,J)=CX1* CGAM    +SX1*SX2* SGAM * SGN                         BESE 520
   ISN 0035            ARG(J)=DARCOS(CSTH(K,J))                                            BESE 530
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ISN 0036           IF(ARG(J) .EQ. 0.0D0) ARG(J) = 0.0001D0                            BESE 540
              C                                                                        BESE 550
              C    ANGLE IN RADS BETWEEN OFFSET SCATTERING PLANES ANDREF PLANE         BESE 560
              C    PSI(J)=DARSIN((DSIN(GAM)*CX2)/DSIN(ARG(J)))                         BESE 570
ISN 0038           PSI(J)=DARSIN((   SGAM    *CX2)/DSIN(ARG(J)))                       BESE 580
              C                                                                        BESE 590
              C                                                                        BESE 600
              C                                                                        BESE 610
ISN 0039           AA=AL*DSIN(ARG(J))                                                  BESE 620
ISN 0040           AB = ARG(J)                                                         BESE 630
ISN 0041           IF(.NOT.OUT) PRINT 22,AB                                            BESE 640
ISN 0043           CALL MIECXU(AB,EPER,EHOZ,DELT)                                      BESE 650
ISN 0044           IF(.NOT.OUT) PRINT 22,AB,EPER,EHOZ,DELT                             BESE 660
              C    CONVERSION FOR VERTICALLY POLARIZED ILLUMINATION                    BESE 670
              C                                                                        BESE 680
ISN 0046           PHI(J)=X(2)+(2*J-3)*DATAN(DTAN(PSI(J))*CX1)                         BESE 690
ISN 0047           E1(J)=EPER*DSIN(PHI(J))                                             BESE 700
ISN 0048           E2(J)=EHOZ*DCOS(PHI(J))                                             BESE 710
              C                                                                        BESE 720
ISN 0049           IF (PHIM .LT. APHI) PHIM=APHI                                       BESE 730
ISN 0051           IF(OUT) GOTO 45                                                     BESE 740
ISN 0053           PRINT 3                                                             BESE 750
ISN 0054         3 FORMAT('0      ARG,            SGN,           SGN2')                BESE 760
ISN 0055           PRINT 1,ARG(J)      ,SGN,SGN2                                       BESE 770
ISN 0056         1 FORMAT('0', 1P4G14.6)                                               BESE 780
ISN 0057        45 CONTINUE                                                            BESE 790
              C                                                                        BESE 800
              C                                                                        BESE 810
              C    FIELD IN REFERENCE SCATTERING PLANE E2                              BESE 820
ISN 0058           E(2) = E2(1)*DCOS(PSI(1)) - E1(1)*DSIN(PSI(1)) +                    BESE 830
                 1   (E2(2)*DCOS(PSI(2)) + E1(2)*DSIN(PSI(2))) * SGN2                  BESE 840
              C                                                                        BESE 850
              C    COMPONENT PERPINDICULAR TO REFERENCE SCATTERING PLANE E1            BESE 860
ISN 0059           E(1)=E2(1)*DSIN(PSI(1))+E1(1)*DCOS(PSI(1))+
                 1   (E1(2)*DCOS(PSI(2))-E2(2)*DSIN(PSI(2)))*SGN2
              C                                                                        BESE 870
              C                                                                        BESE 900
              C    INTENSITY AT A GIVEN POINT ON THE DETECTOR                          BESE 910
ISN 0060           W(K)=E(1)*DCONJG(E(1))+E(2)*DCONJG(E(2))
              C                                                                        BESE 920
              C                                                                        BESE 950
              C                                                                        BESE 960
ISN 0061           IF(DELT1.LT.DELT) DELT1=DELT                                        BESE 970
ISN 0063           IF (OUT) GOTO 35                                                    BESE 980
ISN 0065           OUT=.TRUE.                                                          BESE 990
              C                                                                        BESE1000
ISN 0066           DIA=(AL*WAVE)/PI                                                    BESE1010
ISN 0067           ATETA=X(1)*DEG                                                      BESE1020
ISN 0068           APHI=X(2)*DEG                                                       BESE1030
ISN 0069           PRINT 5                                                             BESE1040
ISN 0070         5 FORMAT(' FN          RAD,          E(1),           E(2),            BESE1050
                 1     W(K),          K')                                              BESE1060
ISN 0071           PRINT 7,FN,DIA,E(1),E(2),W(K),K                                     BESE1070
ISN 0072         7 FORMAT ('0', 1P7G14.6,I5)                                           BESE1080
ISN 0073           PRINT 9                                                             BESE1090
ISN 0074         9 FORMAT('0       PSI(1),          PSI(2),          PHI(1),           BESE1100
                 1          PHI(2)')                                                   BESE1110
ISN 0075           PRINT 13,PSI(1),PSI(2),PHI(1),PHI(2)                                BESE1120
```

```
   ISN 0076        13 FORMAT('0',1P4G14.6)                                          BESE1130
   ISN 0077           PRINT 21                                                      BESE1140
   ISN 0078        21 FORMAT('0      X(1)          X(2)           ARG          DELT1 BESE1150
                    1    BJ1          ATETA          APHI          PHIM')           BESE1160
   ISN 0079           PRINT 17,X(1),X(2),ARG(1) ,DELT1,BJ1,ATETA,APHI,PHIM          BESE1170
   ISN 0080           PRINT 18, ARG(2)                                              BESE1180
   ISN 0081        17 FORMAT('0', 1P8G14.6)                                         BESE1190
   ISN 0082        18 FORMAT( T29,1PG14.6)                                          BESE1200
   ISN 0083           PRINT 11                                                      BESE1210
   ISN 0084        11 FORMAT('0',T6,'X1',T20,'X2',T34,'Y1',T48,'Y2',T62,'XX',T74,'DELT')BESE1220
   ISN 0085           PRINT 19,X1,X2,Y1,Y2,XX,DELT                                  BESE1230
   ISN 0086        19 FORMAT('0',1P6G14.6)                                          BESE1240
   ISN 0087           PRINT 20                                                      BESE1250
   ISN 0088        20 FORMAT('0',T12,'E1(J)', T28, 'E2(J)' ,T28,'J')                BESE1260
   ISN 0089           DO 40 J=1,2                                                   BESE1270
   ISN 0090        40 PRINT 22,E1(J),E2(J),J                                        BESE1280
   ISN 0091        22 FORMAT('0',1P6G14.6)                                          BESE1290
               C                                                                    BESE1300
               C                                                                    BESE1310
               C                                                                    BESE1320
   ISN 0092    35     RETURN                                                        BESE1330
   ISN 0093           END                                                           BESE1340

                   *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
SYMBOL   INTERNAL STATEMENT NUMBERS
E        0005 0058 0059 0060 0060 0060 0060 0071 0071
J        0030 0031 0032 0034 0035 0035 0036 0036 0038 0038 0039 0040 0046 0046 0046 0047 0047 0048 0048
         0055 0089 0090 0090 0090
K        0006 0032 0034 0035 0060 0071 0071
W        0002 0010 0060 0071
X        0002 0010 0025 0026 0027 0028 0046 0067 0068 0079 0079
AA       0039
AB       0040 0041 0043 0044
AL       0006 0039 0066
E1       0005 0047 0058 0058 0059 0059 0090
E2       0005 0048 0058 0058 0059 0059 0090
FN       0007 0023 0071
PI       0018 0019 0066
XX       0009 0085
X1       0009 0085
X2       0009 0085
Y1       0009 0085
Y2       0009 0085
ARG      0010 0035 0036 0036 0038 0039 0040 0055 0079 0080
BJ1      0079
CX1      0026 0034 0046
CX2      0028 0038
DEG      0019 0067 0068
DIA      0066 0071
GAM      0020 0022
GSC      0004 0004 0020 0021 0023
OUT      0006 0013 0041 0044 0051 0063 0065
PHI      0011 0046 0047 0048 0075 0075
PSI      0011 0038 0046 0058 0058 0058 0058 0059 0059 0059 0059 0075 0075
RAD      0007
SGN      0031 0034 0055
SX1      0025 0034
```

```
                    *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
SYMBOL   INTERNAL STATEMENT NUMBERS
SX2      0027  0034
APHI     0049  0049  0068  0079
CGAM     0022  0034
CSTH     0011  0034  0035
DCOS     0022  0026  0028  0048  0058  0058  0059  0059
DELT     0043  0044  0061  0061  0085
DSIN     0025  0027  0038  0039  0047  0058  0058  0059  0059
DTAN     0046
EHOZ     0005  0043  0044  0048
EPER     0005  0043  0044  0047
ONCE     0012  0012  0015  0017
PHIM     0008  0049  0049  0079
SGAM     0021  0034  0038
SGN2     0029  0032  0055  0058  0059
WAVE     0006  0023  0066
ATETA    0067  0079
DATAN    0018  0046
DELT1    0014  0061  0061  0079
BESEL3   0002
DARCOS   0035
DARSIN   0020  0038
DCONJG   0060  0060
MIECXU   0043

                    *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
 LABEL    DEFINED    REFERENCES
    1     0056       0055
    3     0054       0053
    5     0070       0069
    7     0072       0071
    9     0074       0073
   11     0084       0083
   13     0076       0075
   17     0081       0079
   18     0082       0080
   19     0086       0085
   20     0088       0087
   21     0078       0077
   22     0091       0041  0044  0090
   35     0092       0063
   40     0090       0089
   45     0057       0030  0051
  110     0024       0015

                                      /  BESEL3 /    SIZE OF PROGRAM 001242 HEXADECIMAL BYTES

 NAME    TAG    TYPE  ADD.      NAME    TAG    TYPE  ADD.      NAME    TAG    TYPE  ADD.      NAME    TAG    TYPE  ADD.
    F SFA       C*16  000468       J SFA       I*4   000330       K  FA  C    I*4   000010       W SF  XR    R*8   000000
    X  FA XR    R*8   000000      AA S         R*8   000338      AB SFA       R*8   000340      AL  F   C    R*8   000000
   E1 SF        C*16  000488      E2 SF        C*16  0004A8      FN SF   C    R*8   000008      PI SF        R*8   000348
   XX  F   C    R*8   000020      X1  F   C    R*8   000000      X2  F   C    R*8   000008      Y1  F   C    R*8   000010
   Y2  F   C    R*8   000018     ARG SFA       R*8   0003F8     BJ1  F        R*8   000350     CX1 SFA       R*8   000358
  CX2 SFA       R*8   000360     DEG SF        R*8   000368     DIA SF        R*8   000370     GAM SFA       R*8   000378
```

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     GSC  FA        R*8   000408      OUT S    C   I*4   000014      PHI SFA       R*8   000428      PSI SFA       R*8   000438
     RAD       C    R*8   NR          SGN SF       R*8   000380      SX1 SF        R*8   000388      SX2 SF        R*8   000390
    APHI SF         R*8   000398     CGAM SF       R*8   0003A0     CSTH SFA       R*8   000448     DCOS  F  XF    R*8   000000
    DELT SFA        R*8   0003A8     DSIN  FA XF   R*8   000000     DTAN  FA XF    R*8   000000     EHOZ SFA       C*16  0003D8
    EPER SFA        C*16  0003E8     ONCL S        L*4   000334     PHIM SF   C    R*8   000000     SGAM SFA       R*8   0003B0
    SGN2 SF         R*8   0003B8     WAVE  F   C   R*8   000008    ATETA SF        R*8   0003C0    DATAN  F  XF    R*8   000000
   DELTI SF         R*8   0003C8   CDMPY#     XF   C*16  000000   BESEL3           R*8   000300   DARCOS  F  XF    R*8   000000
  DARSIN  F  XF     R*8   000000   IBCOM#     XF   R*8   000000   MIECXU SF  XF          000000

                                   *****  COMMON INFORMATION   *****

     NAME OF COMMON BLOCK  * INPUT*   SIZE OF BLOCK    000018 HEXADECIMAL BYTES

   VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.
         AL   R*8    000000            WAVE  R*8    000008               K  I*4    000010             OUT  L*4    000014

     NAME OF COMMON BLOCK  *  PARM*   SIZE OF BLOCK    000010 HEXADECIMAL BYTES

   VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.
        RAD   R*8    000000 NR           FN  R*8    000008

     NAME OF COMMON BLOCK  *  DIAG*   SIZE OF BLOCK    000008 HEXADECIMAL BYTES

   VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.
       PHIM   R*8    000000

     NAME OF COMMON BLOCK  *  COM7*   SIZE OF BLOCK    000028 HEXADECIMAL BYTES

   VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.
         X1   R*8    000000              X2  R*8    000008              Y1  R*8    000010              Y2  R*8    000018
         XX   R*8    000020

 SOURCE STATEMENT LABELS

   LABEL  ISN  ADDR            LABEL  ISN  ADDR            LABEL  ISN  ADDR            LABEL  ISN  ADDR
    110    24  000670             45   57  000B34             40   90  00119C             35   92  0011F6

 COMPILER GENERATED LABELS

   LABEL  ISN  ADDR            LABEL  ISN  ADDR            LABEL  ISN  ADDR            LABEL  ISN  ADDR
  100001    2  0005C8         100002   17  0005DE         100003   31  00071C         200001   33  000750
  100004   33  00075E         100005   34  000768         100006   37  000814         100007   38  000824
  100008   42  0008F0         100009   43  0008FC         100010   45  00091C         100011   46  000950
  100012   50  000ACE         100013   51  000ADA         100014   53  000AEC         100015   58  000B4A
  200002   60  000EC2         100016   62  000F8C         100017   63  000F94         100018   65  000FA6
  200003   87  001180

 FORMAT STATEMENT LABELS

   LABEL  ISN  ADDR            LABEL  ISN  ADDR            LABEL  ISN  ADDR            LABEL  ISN  ADDR
      3    54  000028              1   56  000051              5   70  00005D              7   72  0000AD
      9    74  0000BB             13   76  000107             21   78  000113             17   81  000180
```

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*LEVEL 2.3.0 (JUNE 78)          BESEL3          OS/360  FORTRAN H EXTENDED          DATE 82.354/10.15.07        PAGE    6

        18   82  00018C            11    84  000195            19    86  0001C0            20    88  0001CC
        22   91  0001E8

*OPTIONS IN EFFECT*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

*OPTIONS IN EFFECT*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

*STATISTICS*     SOURCE STATEMENTS =       92, PROGRAM SIZE =      4674, SUBPROGRAM NAME =BESEL3

*STATISTICS*  NO  DIAGNOSTICS GENERATED

****** END OF COMPILATION ******                                             84K BYTES OF CORE NOT USED

*STATISTICS*  NO  DIAGNOSTICS THIS STEP
```

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REQUESTED OPTIONS: XREF,MAP,OPT=0,GOSTMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
                   SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

             C                                                                          C    10
             C         VIBRA ROUTINE TO COMPUTE SCATTERING COEFF                        C    20
             C                                                                          C    30
             C                                                                          C    40
             C                                                                          C    50
             C                                                                          C    60
  ISN 0002         SUBROUTINE VIBRA(ELEC,EMAG,J,I)                                      C    70
             C                                                                          C    80
             C                                                                          C    90
  ISN 0003         COMMON/COM1/B(1001)/COM3/BETA/COM4/AIRIN,INDICE/COM5/ALPHA           C   100
  ISN 0004         REAL*8 EPS,A1,AAB,AA2,AAB2,AIRIN                                     C   110
  ISN 0005         DOUBLE PRECISION B,DB,ALPHA                                          C   120
  ISN 0006         COMPLEX*16 ELEC(1000),EMAG(1000),ETA,DETA,BETA,MA,INDICE,BB,AB       C   130
  ISN 0007         MA=INDICE/AIRIN                                                      C   140
  ISN 0008         DO 32 I=1,J                                                          C   150
  ISN 0009         M=I+1                                                                C   160
  ISN 0010         BB=AB(M,BETA)                                                        C   170
  ISN 0011         EMAG(I)=(MA*B(M)*BB-DB(M))/(MA*ETA(M)*BB-DETA(M))                    C   180
  ISN 0012         ELEC(I)=(B(M)*BB-MA*DB(M))/(ETA(M)*BB-MA*DETA(M))                    C   190
  ISN 0013         EPS=1.0D-30                                                          C   200
  ISN 0014         A1=DABS(DREAL(EMAG(I)))                                              C   210
  ISN 0015         AAB=DABS(DIMAG(EMAG(I)))                                             C   220
  ISN 0016         AA2=DABS(DREAL(ELEC(I)))                                             C   230
  ISN 0017         AAB2=DABS(DIMAG(ELEC(I)))                                            C   240
  ISN 0018         IF(A1.LT.EPS.OR.AAB.LT.EPS.OR.AA2.LT.EPS.OR.AAB2.LT.EPS) GO TO 33    C   250
  ISN 0020      32 CONTINUE                                                             C   260
  ISN 0021      33 RETURN                                                               C   270
  ISN 0022         END                                                                  C   280

                 *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
SYMBOL  INTERNAL STATEMENT NUMBERS
B        0003  0005  0011  0012
I        0002  0008  0009  0011  0012  0014  0015  0016  0017
J        0002  0008
M        0009  0010  0011  0011  0011  0011  0012  0012  0012  0012
AB       0006  0010
A1       0004  0014  0018
BB       0006  0010  0011  0011  0012  0012
DB       0005  0011  0012
MA       0006  0007  0011  0011  0012  0012
AAB      0004  0015  0018
AA2      0004  0016  0018
EPS      0004  0013  0018  0018  0018  0018
ETA      0006  0011  0012
AAB2     0004  0017  0018
BETA     0003  0006  0010
DABS     0014  0015  0016  0017
DETA     0006  0011  0012
ELEC     0002  0006  0012  0016  0017
EMAG     0002  0006  0011  0014  0015
AIRIN    0003  0004  0007
ALPHA    0003  0005
```

```
                    *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
SYMBOL  INTERNAL STATEMENT NUMBERS
DIMAG   0015  0017
DREAL   0014  0016
VIBRA   0002
INDICE  0003  0006  0007

                    *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
 LABEL   DEFINED    REFERENCES
   32    0020       0008
   33    0021       0018

                                     /   VIBRA /     SIZE OF PROGRAM 0005EA HEXADECIMAL BYTES

     NAME     TAG   TYPE  ADD.        NAME    TAG   TYPE  ADD.        NAME    TAG   TYPE  ADD.        NAME    TAG   TYPE  ADD.
        B  F    C   R*8   000000         I SFA      I*4   0000E4         J  F       I*4   0000E8         M SFA      I*4   0000EC
       AB  F   XF   C*16  000000        A1 S        R*8   0000F8        BB SF       C*16  000128        DB  F  XF   R*8   000000
       MA SF        C*16  000138       AAB S        R*8   000100       AA2 S        R*8   000108       EPS S        R*8   000110
      ETA  F   XF   C*16  000000      AAB2 S        R*8   000118      BETA  FA  C   C*16  000000      DETA  F  XF   C*16  000000
     ELEC SFA  XR   C*16  000000      EMAG SFA XR   C*16  000000     AIRIN  F   C   R*8   000000     ALPHA      C   R*8   NR
    VIBRA           R*4   0000F0    CDMPY#     XF   C*16  000000    CDDVD#     XF   C*16  000000    INDICE  F   C   C*16  000008

                              *****  COMMON INFORMATION  *****

     NAME OF COMMON BLOCK  *  COM1*   SIZE OF BLOCK   001F48 HEXADECIMAL BYTES

    VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
          B    R*8    000000

     NAME OF COMMON BLOCK  *  COM3*   SIZE OF BLOCK   000010 HEXADECIMAL BYTES

    VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
       BETA    C*16   000000

     NAME OF COMMON BLOCK  *  COM4*   SIZE OF BLOCK   000018 HEXADECIMAL BYTES

    VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
      AIRIN    R*8    000000         INDICE  C*16   000008

     NAME OF COMMON BLOCK  *  COM5*   SIZE OF BLOCK   000008 HEXADECIMAL BYTES

    VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
      ALPHA    R*8    000000 NR

 SOURCE STATEMENT LABELS

   LABEL  ISN  ADDR          LABEL  ISN  ADDR          LABEL  ISN  ADDR          LABEL  ISN  ADDR
     32    20  000562          33    21  000578
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*LEVEL 2.3.0 (JUNE 78)          VIBRA          OS/360  FORTRAN H EXTENDED          DATE 82.291/17.21.16          PAGE   3

  COMPILER GENERATED LABELS

    LABEL   ISN   ADDR          LABEL   ISN   ADDR          LABEL   ISN   ADDR          LABEL   ISN   ADDR
   100001    2   0001F0        100002    9   000230        200001   13   0004BA        200002   19   000538
   200003   19   000546        200004   19   000554

*OPTIONS IN EFFECT*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

*OPTIONS IN EFFECT*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

*STATISTICS*     SOURCE STATEMENTS =       21, PROGRAM SIZE =      1514, SUBPROGRAM NAME = VIBRA

*STATISTICS*  NO  DIAGNOSTICS GENERATED

****** END OF COMPILATION ******                                        108K BYTES OF CORE NOT USED
```

```
REQUESTED OPTIONS: XREF,MAP,OPT=0,GOSTMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
                   SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

                C
                C
                C
                C BESSEL SUBROUTINE TO COMPUTE FIRST ORDER RICATTI BESSEL FINCTION
                C
                C
   ISN 0002           SUBROUTINE BESSEL (L,B,II)
   ISN 0003           COMMON/COM5/ALPHA
   ISN 0004           REAL*8 ALPHA,B(401),DENO2
   ISN 0005           COMPLEX*16 ALPHAC,RAP,DENO,ZZ
   ISN 0006           NN=IFIX(SNGL(ALPHA))
   ISN 0007           ZZ=(1.0D+00,0.0D+00)
   ISN 0008           DENO=ZZ
   ISN 0009           ALPHAC=ALPHA*ZZ
   ISN 0010           B(1)=DSIN(ALPHA)
   ISN 0011           B(2)=(DSIN(ALPHA)/ALPHA)-DCOS(ALPHA)
   ISN 0012           IF(NN.GE.7) GO TO 12
   ISN 0014           NN=L
   ISN 0015      12   DO 1 I=3,NN
   ISN 0016           X=I
   ISN 0017           B(I)=(2.0D+00*(X-1.5D+00)/ALPHA)*B(I-1)-B(I-2)
   ISN 0018      1    CONTINUE
   ISN 0019           IF(NN.LT.7) GO TO 13
   ISN 0021           NNN=NN+1
   ISN 0022           DO 2 II=NNN,L
   ISN 0023           DENO=DENO*RAP(II,ALPHAC)
   ISN 0024           DENO2=DREAL(DENO)
   ISN 0025           B(II)=B(NN)/DENO2
   ISN 0026           IF (B(II).LT.1.0D-30) GO TO 13
   ISN 0028      2    CONTINUE
   ISN 0029      13   RETURN
   ISN 0030           END
```

*****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****

SYMBOL	INTERNAL STATEMENT NUMBERS									
B	0002	0004	0010	0011	0017	0017	0017	0025	0025	0026
I	0015	0016	0017	0017	0017					
L	0002	0014	0022							
X	0016	0017								
II	0002	0022	0023	0025	0026					
NN	0006	0012	0014	0015	0019	0021	0025			
ZZ	0005	0007	0008	0009						
NNN	0021	0022								
RAP	0005	0023								
DCOS	0011									
DENO	0005	0008	0023	0023	0024					
DSIN	0010	0011								
IFIX	0006									
SNGL	0006									
ALPHA	0003	0004	0006	0009	0010	0011	0011	0011	0017	
DENO2	0004	0024	0025							
DREAL	0024									

```
*LEVEL 2.3.0 (JUNE 78)        BESSEL          OS/360  FORTRAN H EXTENDED          DATE 82.291/17.21.17       PAGE   2

                        *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
SYMBOL   INTERNAL STATEMENT NUMBERS
ALPHAC  0005  0009  0023
BESSEL  0002

                        *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
 LABEL    DEFINED    REFERENCES
   1      0018       0015
   2      0028       0022
  12      0015       0012
  13      0029       0019  0026

                                          /  BESSEL /     SIZE OF PROGRAM 00044C HEXADECIMAL BYTES

    NAME     TAG    TYPE  ADD.        NAME     TAG    TYPE  ADD.       NAME     TAG    TYPE  ADD.        NAME     TAG    TYPE  ADD.
       B SF   XR    R*8   000000         I SF         I*4   0000F8        L  F         I*4   0000EC         X SF         R*4   0000F0
      II SFA        I*4   0000F4        NN SF         I*4   000018       ZZ SF         C*16  000118       NNN SF         I*4   0000FC
     RAP  F   XF    C*16  000000      DCOS  F   XF    R*8   000000     DENO SFA        C*16  000128      DSIN  F   XF    R*8   000000
   ALPHA FA   C     R*8   000000     DENO2 SF         R*8   000108   CDMPY#       XF   C*16  000000    ALPHAC SFA        C*16  000138
  BESSEL            R*4   000100
                                  *****  COMMON INFORMATION  *****

     NAME OF COMMON BLOCK  *  COM5*   SIZE OF BLOCK    000008 HEXADECIMAL BYTES

    VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
      ALPHA    R*8   000000


 SOURCE STATEMENT LABELS

   LABEL  ISN   ADDR          LABEL  ISN   ADDR          LABEL  ISN   ADDR          LABEL  ISN   ADDR
      12   15  0002AA             1   18  000328             2   28  0003DA            13   29  0003F0

 COMPILER GENERATED LABELS

   LABEL  ISN   ADDR          LABEL  ISN   ADDR          LABEL  ISN   ADDR          LABEL  ISN   ADDR
  100001    2  0001BC        100002   14  0002A2        100003   16  0002B2        100004   19  00033E
  100005   21  00034C        100006   23  00035C

*OPTIONS IN EFFECT*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

*OPTIONS IN EFFECT*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

*STATISTICS*    SOURCE STATEMENTS =     29, PROGRAM SIZE =     1100, SUBPROGRAM NAME =BESSEL

*STATISTICS*  NO  DIAGNOSTICS GENERATED

****** END OF COMPILATION ******                                   108K BYTES OF CORE NOT USED
```

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*LEVEL 2.3.0 (JUNE 78)                    OS/360  FORTRAN H EXTENDED           DATE 82.291/17.21.17        PAGE   1

REQUESTED OPTIONS: XREF,MAP,OPT=0,GOSTMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
                   SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

                 C                                                                  C
                 C        SECOND ORDER RICCATTI-BESSEL FUNCTION CALC.               C
                 C                                                                  C
   ISN 0002            SUBROUTINE NEUMAN(L,NE,I)                                    C
   ISN 0003            COMMON/COM5/ALPHA                                            C
   ISN 0004            REAL*8 NE(1001),ALPHA                                        C
   ISN 0005            NE(1)=DCOS(ALPHA)                                            C
   ISN 0006            NE(2)=(DCOS(ALPHA)/ALPHA)+DSIN(ALPHA)                        C
   ISN 0007            IF((L-2).LE.0.0) GO TO 52                                    C
   ISN 0009            DO 53 I=3,L,1                                                C
   ISN 0010            X=DBLE(FLOAT(I))                                             C
   ISN 0011            NE(I)=(2.0D+00*(X-1.5D+00)/ALPHA)*NE(I-1)-NE(I-2)            C
   ISN 0012            IF(NE(I).GT.1.0D+30) GO TO 52                                C
   ISN 0014        53  CONTINUE                                                     C
   ISN 0015        52  RETURN                                                       C
   ISN 0016            END                                                          C

                    *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
SYMBOL   INTERNAL STATEMENT NUMBERS
I        0002  0009  0010  0011  0011  0011  0012
L        0002  0007  0009
X        0010  0011
NE       0002  0004  0005  0006  0011  0011  0011  0012
DBLE     0010
DCOS     0005  0006
DSIN     0006
ALPHA    0003  0004  0005  0006  0006  0006  0011
FLOAT    0010
NEUMAN   0002

                    *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
 LABEL    DEFINED     REFERENCES
   52     0015        0007  0012
   53     0014        0009

                                     /  NEUMAN /    SIZE OF PROGRAM 00029A HEXADECIMAL BYTES

     NAME    TAG   TYPE  ADD.       NAME   TAG   TYPE  ADD.       NAME   TAG   TYPE  ADD.       NAME   TAG   TYPE  ADD.
        I SFA      I*4   0000B0        L F       I*4   0000B4        X SF      R*4   0000B8        NE SF  XR  R*8   000000
     DCOS  F  XF   R*8   000000     DSIN  F  XF  R*8   000000     ALPHA  FA  C R*8   000000     NEUMAN       I*4   0000BC

                               *****  COMMON INFORMATION  *****

      NAME OF COMMON BLOCK  *  COM5*   SIZE OF BLOCK    000008 HEXADECIMAL BYTES

     VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
        ALPHA   R*8    000000
```

```
*LEVEL 2.3.0 (JUNE 78)                    OS/360  FORTRAN H EXTENDED           DATE 82.291/17.21.20        PAGE    1

REQUESTED OPTIONS: XREF,MAP,OPT=0,GOSIMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
                   SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSIMT XREF NOALC NOANSF TERM IBM FLAG(I)

                C                                                                             C      10
                C                                                                             C      20
                C        FIRST ORDER RICATTI-BESSEL FUNCTION DERIVATIVE CALCULATION           C      30
                C                                                                             C      40
   ISN 0002            DOUBLE PRECISION FUNCTION DB(M)                                        C      50
   ISN 0003            COMMON/COM1/B(1001)/COM5/ALPHA                                         C      60
   ISN 0004            DOUBLE PRECISION B,ALPHA                                               C      70
   ISN 0005            X=DBLE(FLOAT(M))                                                       C      80
   ISN 0006            DB=B(M-1)-((X-1.0D0)/ALPHA)*B(M)                                       C      90
   ISN 0007            RETURN                                                                 C     100
   ISN 0008            END                                                                    C     110

                       *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
SYMBOL   INTERNAL STATEMENT NUMBERS
B        0003  0004  0006  0006
M        0002  0005  0006  0006
X        0005  0006
DB       0002  0006
DBLE     0005
ALPHA    0003  0004  0006
FLOAT    0005

                                                        /       DB /     SIZE OF PROGRAM 000188 HEXADECIMAL BYTES

      NAME    TAG   TYPE  ADD.        NAME    TAG   TYPE  ADD.        NAME    TAG   TYPE  ADD.        NAME    TAG   TYPE  ADD.
         B  F   C   R*8   000000         M  FA      I*4   000094         X SF       R*4   000098        DB S        R*8   0000A0
     ALPHA  F   C   R*8   000000

                                         *****  COMMON INFORMATION   *****

      NAME OF COMMON BLOCK  *  COM1*   SIZE OF BLOCK    001F48 HEXADECIMAL BYTES

     VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
            B   R*8     000000

      NAME OF COMMON BLOCK  *  COM5*   SIZE OF BLOCK    000008 HEXADECIMAL BYTES

     VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
        ALPHA   R*8     000000


  COMPILER GENERATED LABELS

    LABEL  ISN   ADDR          LABEL  ISN   ADDR          LABEL  ISN   ADDR          LABEL  ISN   ADDR
   100001    2  000008

*OPTIONS IN EFFECT*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

*OPTIONS IN EFFECT*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSIMT XREF NOALC NOANSF TERM IBM FLAG(I)
```

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*LEVEL 2.3.0 (JUNE 78)                    OS/360  FORTRAN H EXTENDED           DATE 82.291/17.21.17       PAGE   2

  SOURCE STATEMENT LABELS

    LABEL  ISN   ADDR            LABEL  ISN   ADDR            LABEL  ISN   ADDR            LABEL  ISN   ADDR
       53   14  000228              52   15  00023E

  COMPILER GENERATED LABELS

    LABEL  ISN   ADDR            LABEL  ISN   ADDR            LABEL  ISN   ADDR            LABEL  ISN   ADDR
   100001    2  000108          100002    9  00018A          100003   10  000192

*OPTIONS IN EFFECT*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

*OPTIONS IN EFFECT*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

*STATISTICS*     SOURCE STATEMENTS =       15, PROGRAM SIZE =       666, SUBPROGRAM NAME =NEUMAN

*STATISTICS*  NO  DIAGNOSTICS GENERATED

****** END OF COMPILATION ******                                     108K BYTES OF CORE NOT USED
```

```
*LEVEL 2.3.0 (JUNE 78)                    OS/360  FORTRAN H EXTENDED          DATE 82.291/17.21.20       PAGE   1

REQUESTED OPTIONS: XREF,MAP,OPT=0,GOSTMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
                   SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

                C                                                                         C      10
                C                                                                         C      20
                C          SECOND ORDER RICCATTI-BESSEL DERIVATIVE COMPUTATION            C      30
                C                                                                         C      40
                C                                                                         C      50
  ISN 0002            DOUBLE PRECISION FUNCTION DN(M)                                     C      60
  ISN 0003            COMMON/COM2/NE(1001)/COM5/ALPHA                                     C      70
  ISN 0004            DOUBLE PRECISION NE,ALPHA                                           C      80
  ISN 0005            X DBLE(FLOAT(M))                                                    C      90
  ISN 0006            DN NE(M-1)-((X-1.D0)/ALPHA)*NE(M)                                   C     100
  ISN 0007            RETURN                                                              C     110
  ISN 0008            END                                                                 C     120

                *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
SYMBOL   INTERNAL STATEMENT NUMBERS
M        0002  0005  0006  0006
X        0005  0006
DN       0002  0006
NE       0003  0004  0006  0006
DBLE     0005
ALPHA    0003  0004  0006
FLOAT    0005

                                        /     DN /     SIZE OF PROGRAM 000188 HEXADECIMAL BYTES

     NAME   TAG   TYPE  ADD.        NAME   TAG  TYPE  ADD.        NAME   TAG  TYPE  ADD.        NAME   TAG  TYPE  ADD.
        M   FA    I*4   000094         X SF      R*4   000098        DN S      R*8   0000A0        NE  F   C  R*8   000000
    ALPHA   F   C R*8   000000

                               *****  COMMON INFORMATION  *****

     NAME OF COMMON BLOCK  *  COM2*   SIZE OF BLOCK   001F48 HEXADECIMAL BYTES

    VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
          NE   R*8   000000

     NAME OF COMMON BLOCK  *  COM5*   SIZE OF BLOCK   000008 HEXADECIMAL BYTES

    VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
       ALPHA   R*8   000000

 COMPILER GENERATED LABELS

   LABEL  ISN  ADDR          LABEL  ISN  ADDR          LABEL  ISN  ADDR          LABEL  ISN  ADDR
  100001    2  0000D8

*OPTIONS IN EFFECT*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
```

```
*LEVEL 2.3.0 (JUNE 78)                    OS/360  FORTRAN H EXTENDED          DATE 82.291/17.21.20       PAGE   2
*STATISTICS*     SOURCE STATEMENTS =       7, PROGRAM SIZE =      392, SUBPROGRAM NAME =    DB
*STATISTICS*  NO  DIAGNOSTICS GENERATED
****** END OF COMPILATION ******                                  108K BYTES OF CORE NOT USED
```

```
*LEVEL 2.3.0 (JUNE 78)                    OS/360   FORTRAN H EXTENDED           DATE 82.291/17.21.21       PAGE    1

REQUESTED OPTIONS: XREF,MAP,OPT=0,GOSTMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
                   SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

                  C                                                                       C      10
                  C                                                                       C      20
                  C         ROUTINE TO COMPUTE RATIO OF TWO BESSEL FCTS OF CONSEC ORDER   C      30
                  C                                                                       C      40
                  C                                                                       C      50
   ISN 0002             COMPLEX FUNCTION AB*16(M,BETA)                                    C      60
   ISN 0003             COMPLEX*16 RAP,BETA                                               C      70
   ISN 0004             DW=DBLE(FLOAT(M-1))                                               C      80
   ISN 0005             AB=-DW/BETA+RAP(M,BETA)                                           C      90
   ISN 0006             RETURN                                                            C     100
   ISN 0007             END                                                               C     110

                      *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
SYMBOL   INTERNAL STATEMENT NUMBERS
M        0002  0004  0005
AB       0002  0005
DW       0004  0005
RAP      0003  0005
BETA     0002  0003  0005  0005
DBLE     0004
FLOAT    0004

                                                  /      AB /     SIZE OF PROGRAM 0001E4 HEXADECIMAL BYTES

     NAME    TAG   TYPE  ADD.        NAME    TAG   TYPE  ADD.        NAME    TAG   TYPE  ADD.        NAME    TAG   TYPE  ADD.
        M  FA      I*4   00009C       AB S         C*16  0000A8       DW SF        R*4   0000A0       RAP   F  XF    C*16  000000
     BETA  FA      C*16  0000B8    CDDVD#     XF   C*16  000000


  COMPILER GENERATED LABELS

    LABEL  ISN   ADDR            LABEL  ISN   ADDR            LABEL  ISN   ADDR            LABEL  ISN   ADDR
   100001    2  0000FC

*OPTIONS IN EFFECT*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

*OPTIONS IN EFFECT*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

*STATISTICS*     SOURCE STATEMENTS =       6, PROGRAM SIZE =       484, SUBPROGRAM NAME =     AB

*STATISTICS*  NO  DIAGNOSTICS GENERATED

****** END OF COMPILATION ******                                  108K BYTES OF CORE NOT USED
```

```
*LEVEL 2.3.0 (JUNE 78)                    OS/360  FORTRAN H EXTENDED          DATE 82.291/17.21.20       PAGE   2
*OPTIONS IN EFFECT*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)
*STATISTICS*     SOURCE STATEMENTS =        7, PROGRAM SIZE         392, SUBPROGRAM NAME =    DN
*STATISTICS*  NO  DIAGNOSTICS GENERATED
****** END OF COMPILATION ******                                   108K BYTES OF CORE NOT USED
```

```
REQUESTED OPTIONS: XREF,MAP,OPT=0,GOSTMT

OPTIONS IN EFFECT: NAME(MA''') NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
                   SOURCE     IC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

                  C                                                                        C     10
                  C                                                                        C     20
   ISN 0002              COMPLEX FUNCTION RAP*16(I,Z)                                      C     30
   ISN 0003              COMPLEX*16 Z,AR(5000),BR(5000),S,V                                C     40
                  C                                                                        C     50
   ISN 0004              CALL FRAC(I,Z,AR,BR,K)                                            C     60
                  C                                                                        C     70
   ISN 0005              S=AR(1)                                                           C     80
   ISN 0006              V=(1.0D0,0.0D0)                                                   C     90
   ISN 0007              L=K-1                                                             C    100
   ISN 0008              DO 2 J=1,L                                                        C    110
   ISN 0009              S=S*AR(J+1)                                                       C    120
   ISN 0010              V=V*BR(J)                                                         C    130
   ISN 0011              IF(J.EQ.4999) GO TO 5                                             C    140
   ISN 0013       2      CONTINUE                                                          C    150
   ISN 0014       5      RAP=S/V                                                           C    160
   ISN 0015              RETURN                                                            C    170
   ISN 0016              END                                                               C    180

                     *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
SYMBOL  INTERNAL STATEMENT NUMBERS
I        0002  0004
J        0008  0009  0010  0011
K        0004  0007
L        0007  0008
S        0003  0005  0009  0009  0014
V        0003  0006  0010  0010  0014
Z        0002  0003  0004
AR       0003  0004  0005  0009
BR       0003  0004  0010
RAP      0002  0014
FRAC     0004

                     *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
 LABEL   DEFINED   REFERENCES
   2      0013      0008
   5      0014      0011

                                   /    RAP /     SIZE OF PROGRAM 0273B2 HEXADECIMAL BYTES

     NAME    TAG   TYPE  ADD.       NAME    TAG   TYPE  ADD.       NAME    TAG   TYPE  ADD.       NAME    TAG   TYPE  ADD.
        I SFA      I*4   0000B8        J SF       I*4   0000BC        K SFA      I*4   0000C0        L SF       I*4   0000C4
        S SF       C*16  0000C8        V SF       C*16  0000D8        Z SFA      C*16  0000F8       AR SFA      C*16  000108
       BR SFA      C*16  013988      RAP S        C*16  0000F8     FRAC SF   XF        000000   CDDVD#     XF   C*16  000000
   CDMPY#     XF   C*16  000000

  SOURCE STATEMENT LABELS

    LABEL  ISN   ADDR          LABEL  ISN   ADDR          LABEL  ISN   ADDR          LABEL  ISN   ADDR
```

```
*LEVEL 2.3.0 (JUNE 78)                    OS/360  FORTRAN H EXTENDED          DATE 82.291/17.21.21      PAGE   2

       2   13  027318              5    14  02732E

  COMPILER GENERATED LABELS

    LABEL   ISN   ADDR            LABEL   ISN   ADDR            LABEL   ISN   ADDR            LABEL   ISN   ADDR
   100001     2  027248          100002     9  02728A

*OPTIONS IN EFFECT*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

*OPTIONS IN EFFECT*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

*STATISTICS*     SOURCE STATEMENTS =       15, PROGRAM SIZE =    160690, SUBPROGRAM NAME =    RAP

*STATISTICS*  NO  DIAGNOSTICS GENERATED

****** END OF COMPILATION ******                                        108K BYTES OF CORE NOT USED
```

```
*LEVEL 2.3.0 (JUNE 78)                    OS/360  FORTRAN H EXTENDED            DATE 82.291/17.21.22        PAGE   1

REQUESTED OPTIONS: XREF,MAP,OPT=0,GOSTMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
                   SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

                C                                                                                    C      10
                C                                                                                    C      20
   ISN 0002           SUBROUTINE FRAC(I,Z,AR,BR,K)                                                   C      30
                C                                                                                    C      40
                C                                                                                    C      50
   ISN 0003           COMPLEX*16 Z,AR(5000),BR(5000),AA(5000),AAA                                    C      60
   ISN 0004           DOUBLE PRECISION W,YY                                                          C      70
   ISN 0005           AR(1)=AAA(1,I,Z)                                                               C      80
   ISN 0006           AA(2)=AAA(2,I,Z)                                                               C      90
   ISN 0007           AR(2)=AA(2)+1.0/AR(1)                                                          C     100
   ISN 0008           BR(1)=AA(2)                                                                    C     110
   ISN 0009           DO 1 K=3,5000                                                                  C     120
   ISN 0010           AA(K)=AAA(K,I,Z)                                                               C     130
   ISN 0011           AR(K)=AA(K)+1.0D0/AR(K-1)                                                      C     140
   ISN 0012           BR(K-1)=AA(K)+1.0D0/BR(K-2)                                                    C     150
   ISN 0013           W=AR(K)*DCONJG(AR(K))                                                          C     160
   ISN 0014           YY=BR(K-1)*DCONJG(BR(K-1))                                                     C     170
   ISN 0015           IF(W.EQ.YY) GO TO 2                                                            C     180
   ISN 0017     1     CONTINUE                                                                       C     190
   ISN 0018     2     RETURN                                                                         C     200
   ISN 0019           END                                                                            C     210

                          *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
SYMBOL   INTERNAL STATEMENT NUMBERS
I        0002  0005  0006  0010
K        0002  0009  0010  0010  0011  0011  0011  0012  0012  0012  0013  0013  0014  0014
W        0004  0013  0015
Z        0002  0003  0005  0006  0010
AA       0003  0006  0007  0008  0010  0011  0012
AR       0002  0003  0005  0007  0007  0011  0011  0013  0013
BR       0002  0003  0008  0012  0012  0014  0014
YY       0004  0014  0015
AAA      0003  0005  0006  0010
FRAC     0002
DCONJG   0013  0014

                          *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
 LABEL   DEFINED   REFERENCES
   1      0017      0009
   2      0018      0015

                                             /   FRAC /    SIZE OF PROGRAM 013DF4 HEXADECIMAL BYTES

    NAME   TAG    TYPE  ADD.       NAME   TAG    TYPE  ADD.      NAME   TAG    TYPE  ADD.      NAME   TAG    TYPE  ADD.
       I  FA      I*4   0000DC        K SFA      I*4   0000E0       W S        R*8   0000E8       Z  FA      C*16  0000F8
      AA SF       C*16  000108       AR SFA XR   C*16  000000      BR SFA XR   C*16  000000      YY S        R*8   0000F0
     AAA  F  XF   C*16  000000     FRAC          R*4   0000E4   CDMPY#    XF   C*16  000000   CDDVD#    XF   C*16  000000
```

```
*LEVEL 2.3.0 (JUNE 78)                    OS/360  FORTRAN H EXTENDED          DATE 82.291/17.21.22        PAGE   2
  SOURCE STATEMENT LABELS

    LABEL   ISN   ADDR             LABEL   ISN   ADDR           LABEL  ISN   ADDR           LABEL  ISN   ADDR
       1     17  013D44                2    18  013D5A

  COMPILER GENERATED LABELS

    LABEL   ISN   ADDR             LABEL   ISN   ADDR           LABEL  ISN   ADDR           LABEL  ISN   ADDR
   100001     2  013A20           100002    10  013B0C          200001   16  013D36

*OPTIONS IN EFFECT*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

*OPTIONS IN EFFECT*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

*STATISTICS*    SOURCE STATEMENTS =      18, PROGRAM SIZE =    81396, SUBPROGRAM NAME =  FRAC

*STATISTICS*  NO  DIAGNOSTICS GENERATED

****** END OF COMPILATION ******                                   108K BYTES OF CORE NOT USED
```

```
*LEVEL 2.3.0 (JUNE 78)                    OS/360  FORTRAN H EXTENDED          DATE 82.291/17.21.23       PAGE   1

REQUESTED OPTIONS: XREF,MAP,OPT=0,GOSTMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
                   SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

                C                                                                              C      10
                C                                                                              C      20
   ISN 0002          COMPLEX FUNCTION AAA*16(M,I,Z)                                            C      30
                C                                                                              C      40
                C                                                                              C      50
   ISN 0003          COMPLEX*16 Z                                                              C      60
   ISN 0004          DOUBLE PRECISION W,WW                                                     C      70
   ISN 0005          WW=DBLE(FLOAT(I))                                                         C      80
   ISN 0006          MM=DBLE(FLOAT(M))                                                         C      90
   ISN 0007          W=WW-0.5D0                                                                C     100
   ISN 0008          AAA=((-1)**(M+1))*2.0D0*(W+MM-1.0D0)/Z                                    C     110
   ISN 0009          RETURN                                                                    C     120
   ISN 0010          END                                                                       C     130

                    *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
SYMBOL  INTERNAL STATEMENT NUMBERS
I       0002  0005
M       0002  0006  0008
W       0004  0007  0008
Z       0002  0003  0008
MM      0006  0008
WW      0004  0005  0007
AAA     0002  0008
DBLE    0005  0006
FLOAT   0005  0006

                                        /     AAA /    SIZE OF PROGRAM 000296 HEXADECIMAL BYTES

     NAME    TAG   TYPE  ADD.       NAME    TAG   TYPE  ADD.       NAME    TAG   TYPE  ADD.       NAME    TAG   TYPE  ADD.
        I  FA      I*4   0000C4        M  FA      I*4   0000C8        W SF       R*8   0000D0        Z  F        C*16  0000E8
       MM SF       I*4   0000CC       WW SF       R*8   0000D8      AAA S        C*16  0000F8   CDDVD#     XF    C*16  000000
   FIXPI#     XF   I*4   000000


  COMPILER GENERATED LABELS

    LABEL  ISN   ADDR          LABEL  ISN   ADDR          LABEL  ISN   ADDR          LABEL  ISN   ADDR
   100001    2  00013C

*OPTIONS IN EFFECT*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

*OPTIONS IN EFFECT*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

*STATISTICS*     SOURCE STATEMENTS =       9, PROGRAM SIZE =       662, SUBPROGRAM NAME =   AAA

*STATISTICS*  NO  DIAGNOSTICS GENERATED

****** END OF COMPILATION ******                                 108K BYTES OF CORE NOT USED
```

```
*LEVEL 2.3.0 (JUNE 78)                    OS/360  FORTRAN H EXTENDED          DATE 82.291/17.21.24       PAGE   1

REQUESTED OPTIONS: XREF,MAP,OPT=0,GOSTMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
                   SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

                C                                                                         C       10
                C                                                                         C       20
                C         HANKEL FUNCTION AND DERIVATIVE CALCULATION                      C       30
                C                                                                         C       40
                C                                                                         C       50
   ISN 0002           COMPLEX FUNCTION ETA*16(J)                                          C       60
   ISN 0003           COMMON/COM1/B(1001)/COM2/NE(1001)                                   C       70
   ISN 0004           COMPLEX*16 Z                                                        C       80
   ISN 0005           DOUBLE PRECISION B,NE                                               C       90
   ISN 0006           Z=(0.0D0,1.0D0)                                                     C      100
   ISN 0007           ETA=B(J)+Z*NE(J)                                                    C      110
   ISN 0008           RETURN                                                              C      120
   ISN 0009           END                                                                 C      130

                   *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
SYMBOL  INTERNAL STATEMENT NUMBERS
B       0003  0005  0007
J       0002  0007  0007
Z       0004  0006  0007
NE      0003  0005  0007
ETA     0002  0007

                                                     /    ETA /    SIZE OF PROGRAM 0001A6 HEXADECIMAL BYTES

     NAME    TAG   TYPE  ADD.        NAME   TAG   TYPE  ADD.        NAME   TAG   TYPE  ADD.        NAME   TAG   TYPE  ADD.
       B  F   C    R*8   000000        J  F       I*4   000090        Z SF         C*16  000098       NE  F   C   R*8   000000
     ETA S         C*16  0000A8     CDMPY#   XF   C*16  000000
                                     *****  COMMON INFORMATION   *****

     NAME OF COMMON BLOCK  *  COM1*   SIZE OF BLOCK    001F48 HEXADECIMAL BYTES

     VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
          B     R*8    000000

     NAME OF COMMON BLOCK  *  COM2*   SIZE OF BLOCK    001F48 HEXADECIMAL BYTES

     VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
          NE    R*8    000000

  COMPILER GENERATED LABELS

   LABEL  ISN   ADDR          LABEL  ISN   ADDR          LABEL  ISN   ADDR          LABEL  ISN   ADDR
  100001    2  0000F8

*OPTIONS IN EFFECT*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

*OPTIONS IN EFFECT*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)
```

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*LEVEL 2.3.0 (JUNE 78)                    OS/360   FORTRAN H EXTENDED          DATE 82.291/17.21.26        PAGE   1

REQUESTED OPTIONS: XREF,MAP,OPT=0,GOSTMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
                   SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

              C                                                                                C    10
   ISN 0002          COMPLEX FUNCTION DETA*16(M)                                               C    20
   ISN 0003          COMPLEX*16 Z                                                              C    30
   ISN 0004          DOUBLE PRECISION DB,DN                                                    C    40
   ISN 0005          Z=(0.0D0,1.0D0)                                                           C    50
   ISN 0006          DETA=DB(M)+Z*DN(M)                                                        C    60
   ISN 0007          RETURN                                                                    C    70
   ISN 0008          END                                                                       C    80

                *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
SYMBOL  INTERNAL STATEMENT NUMBERS
M       0002  0006  0006
Z       0003  0005  0006
DB      0004  0006
DN      0004  0006
DETA    0002  0006

                                              /    DETA /     SIZE OF PROGRAM 0001BC HEXADECIMAL BYTES

      NAME     TAG    TYPE  ADD.         NAME     TAG   TYPE  ADD.        NAME    TAG   TYPE  ADD.        NAME    TAG   TYPE  ADD.
         M   FA       I*4   000090          Z SF        C*16  000098        DB  F  XF    R*8   000000        DN  F  XF    R*8   000000
      DETA S          C*16  0000A8       CDMPY#     XF  C*16  000000

  COMPILER GENERATED LABELS

    LABEL  ISN   ADDR           LABEL  ISN   ADDR           LABEL  ISN   ADDR           LABEL  ISN   ADDR
   100001    2  0000F8

*OPTIONS IN EFFECT*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

*OPTIONS IN EFFECT*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

*STATISTICS*     SOURCE STATEMENTS =       7, PROGRAM SIZE =      444, SUBPROGRAM NAME =  DETA

*STATISTICS*  NO  DIAGNOSTICS GENERATED

****** END OF COMPILATION ******                                      108K BYTES OF CORE NOT USED
```

```
*LEVEL 2.3.0 (JUNE 78)                    OS/360  FORTRAN H EXTENDED          DATE 82.291/17.21.24       PAGE   2
*STATISTICS*    SOURCE STATEMENTS =       8, PROGRAM SIZE =      422, SUBPROGRAM NAME =   ETA
*STATISTICS*  NO  DIAGNOSTICS GENERATED
****** END OF COMPILATION ******                                    108K BYTES OF CORE NOT USED
```

```
*LEVEL 2.3.0 (JUNE 78)                    OS/360   FORTRAN H EXTENDED            DATE 82.291/17.21.27        PAGE    1

REQUESTED OPTIONS: XREF,MAP,OPT=0,GOSTMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
                   SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

                  C
                  C
                  C        LEGENDRE POLYS
                  C
                  C
      ISN 0002           SUBROUTINE POLY(L,PO,PA,TETA)
      ISN 0003           REAL*8 PO(1000),PA(1000),TETA,G
      ISN 0004           PO(1)=0.10000D+01
      ISN 0005           PO(2)=3.0D0*DCOS(TETA)
      ISN 0006           PA(1)=DCOS(TETA)
      ISN 0007           PA(2)=3.0D0*DCOS(2.0D0*TETA)
      ISN 0008           DO 2 I=3,L,1
      ISN 0009           G=DCOS(TETA)*PO(I-1)
      ISN 0010           PO(I)=G+G-PO(I-2)+(G-PO(I-2))/DBLE(FLOAT(I-1))
      ISN 0011           PA(I)=DBLE(FLOAT(I))*PO(I)*DCOS(TETA)-DBLE(FLOAT(I+1))*PO(I-1)
      ISN 0012    2      CONTINUE
      ISN 0013           RETURN
      ISN 0014           END

                    *****F O R T R A N    C R O S S    R E F E R E N C E    L I S T I N G*****
SYMBOL   INTERNAL STATEMENT NUMBERS
G        0003  0009  0010  0010  0010
I        0008  0009  0010  0010  0010  0010  0011  0011  0011  0011  0011
L        0002  0008
PA       0002  0003  0006  0007  0011
PO       0002  0003  0004  0005  0009  0010  0010  0010  0011  0011
DBLE     0010  0011  0011
DCOS     0005  0006  0007  0009  0011
POLY     0002
TETA     0002  0003  0005  0006  0007  0009  0011
FLOAT    0010  0011  0011

                    *****F O R T R A N    C R O S S    R E F E R E N C E    L I S T I N G*****
 LABEL   DEFINED   REFERENCES
   2     0012      0008

                                                  /    POLY /    SIZE OF PROGRAM 00038A HEXADECIMAL BYTES

     NAME    TAG   TYPE  ADD.        NAME    TAG   TYPE  ADD.        NAME    TAG   TYPE  ADD.        NAME    TAG   TYPE  ADD.
       G SF        R*8   0000C0         I SFA      I*4   0000B4         L F        I*4   0000B8        PA S    XR    R*8   000000
      PO SF   XR   R*8   000000      DCOS  F  XF   R*8   000000      POLY          R*4   0000BC      TETA  FA        R*8   0000C8


  SOURCE STATEMENT LABELS

   LABEL  ISN   ADDR           LABEL  ISN   ADDR           LABEL  ISN   ADDR           LABEL  ISN   ADDR
     2     12   000302

  COMPILER GENERATED LABELS
```

```
*LEVEL 2.3.0 (JUNE 78)                    OS/360   FORTRAN H EXTENDED            DATE 82.291/17.21.27        PAGE   2

    LABEL   ISN    ADDR            LABEL   ISN    ADDR            LABEL   ISN    ADDR            LABEL   ISN    ADDR
   100001     2   00012C          100002     9   0001A6          100003    13   000318

*OPTIONS IN EFFECT*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

*OPTIONS IN EFFECT*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(I)

*STATISTICS*     SOURCE STATEMENTS =       13, PROGRAM SIZE =       906, SUBPROGRAM NAME =  POLY

*STATISTICS*  NO  DIAGNOSTICS GENERATED

****** END OF COMPILATION ******                                      108K BYTES OF CORE NOT USED

*STATISTICS*  NO  DIAGNOSTICS THIS STEP
```

```
0

 1
  1.670 -0.330000
 1
 15.000
0 TMIN,     TMAX,      A,        Z,        WAVE

 3.40000D-02   .170000       17.0000       250.000       .632800
```

```
MIE COEFFICIENTS FOR X =      15.00, REF.INDEX =   1.670 -0.3300001

    QEXT =    2.301859, QSCA =    1.203147      QABS=        1.09871


         1        .5064653            .1379551            .4935929            -.1393563
         2        .5297321           -.1333192            .4688572             .1375290
         3        .4218656            .1093197            .5840144            -.1159866
         4        .6201383           -5.260179D-02        .3652750            5.728591D-02
         5        .3773943           -3.309797D-02        .6445963            4.161909D-02
         6        .5569460            .1073361            .4301472            -.1392445
         7        .5526391           -.1017268            .4207740             .1418122
         8        .3944218           -2.740722D-03        .6704453            1.130071D-02
         9        .5247071            9.065384D-02        .4612173            -.1773142
        10        .5730342           -2.967354D-02        .3153609            6.257319D-02
        11        .4821615           -5.544839D-02        .5539805             .2055319
        12        .4703139           -7.624024D-04        .7355320            2.459796D-03
        13        .4974840           -1.395567D-02        .6255411            -.2345961
        14        .4507895           -5.926068D-02        .3904934            -.2867673
        15        .3346948           -5.465376D-02        .2040013            -.2025609
        16        .1963949           -7.998746D-03       9.664416D-02        -9.772082D-02
        17       7.958659D-02         1.648615D-02       3.965646D-02        -3.249231D-02
        18       2.165339D-02         1.041643D-02       1.285128D-02        -7.470837D-03
        19       4.506663D-03         3.316420D-03       3.253383D-03        -1.199246D-03
        20       7.793423D-04         7.671973D-04       6.615229D-04        -1.176307D-04
        21       1.152818D-04         1.430563D-04       1.097784D-04         3.746295D-08
        22       1.494369D-05         2.242514D-05       1.510305D-05         2.505638D-06
        23       1.739678D-06         3.042198D-06       1.769496D-06         5.584542D-07
        24       1.850964D-07         3.651073D-07       1.819451D-07         8.143026D-08
        25       1.817105D-08         3.936383D-08       1.681650D-08         9.451004D-09
        26       1.653388D-09         3.852245D-09       1.419370D-09         9.375439D-10
        27       1.397522D-10         3.446746D-10       1.104677D-10         8.232188D-11
        28       1.098952D-11         2.834827D-11       7.975826D-12         6.525251D-12
        29       8.050636D-13         2.152473D-12       5.363688D-13         4.726311D-13
        30       5.502329D-14         1.514330D-13       3.369624D-14         3.153772D-14
        31       3.765032D-15         2.726291D-14       2.123833D-15         1.874241D-14
        32        .0                  .0                  .0                  .0
XUPP=        .10846085
XUPP=        .65636487

   .103512

   .103512       89.9817       -3.67537        88.6206       -8.49324       -5.47233D-02

     ARG,          SGN,          SGN2

   .103512       1.00000        1.00000

   .116002

   .116002       81.3012       -1.85329        79.7375       -7.54363       -7.15336D-02

     ARG,          SGN,          SGN2

   .116002      -1.00000        1.00000
FN             RAD,          E(1),          E(2),                W(K),         K

   17.6081       3.02140       60.2334       -1.99126       157.664      -14.7656      28708.1       1

      PSI(1),          PSI(2),         PHI(1)     ,               PHI(2)
```

```
.163523     .145850     .196785     .504369
  X(1)        X(2)        ARG        DELT1          BJ1        ATETA         APHI        PHIM
.108461     .359364     .103512      .0             .0         6.21435       20.5900     .0
                        .116002
  X1          X2          Y1          Y2            XX         DELT
81.3012     79.7375     -1.85329    -7.54363      -7.16559D-02 -7.15336D-02
      E1(J)        J2(J)
17.5930     -.718598    86.9103     -8.32932               1
39.2892     -.895610    69.8086     -6.60429               2
COLLECTED POWER (P/I),MAX=   2.19990D-08 MIN=   4.51092D-11   MEAN=  1.10221D-08
VISIBILITY=       .99590738
```

APPENDIX C

PROCEDURES FOR PSI CALIBRATION AND DATA RECORDING

I. Equipment Required

Oscilloscope: Tektronix, Model 7904 or equivalent
Digital VOM: Data Precision Model 245 or equivalent
Frequency counter: Hewlett-Packard, Model 5245L or equivalent
Pulse generator: E-H Research Laboratories, Model 139B or equivalent
Pulse generator Hewlett-Packard; Model 8007B or equivalent
Regulated 0-12 VDC voltage source: Lambda, Model LPD 421 or equivalent

II. Recording and Playback Components

Calibration of the system begins with the calibration of the recording and playback components. Tape recorder instructions apply to the Honeywell Model 5600 tape recording system equipped with Type 16775816-003 FM record amplifiers and Type 16775395-001 FM reproduce amplifiers. The system records at 60 ips, hence playback at 15 ips requires a 10 kHz filter (Type 1677539-001) inserted in the "A" filter position on the reproduce amplifier card. The calibration is to be performed on the record and reproduce amplifiers for each channel in use. Unless otherwise directed, oscilloscope amplifier inputs are high impedance, DC coupled.

A. Record Amplifier

1. Set the recorder POWER and CALIBRATION switches to ON and allow at least five minutes for warm-up. Set SPEED switch and "B" jumper pin (on control panel) to 60 ips. Remove power whenever a printed circuit card is removed or installed.
2. Connect an oscilloscope to monitor the signal at TP1 and TP2 (ground). (TP1 and TP2 are the white and black test jacks at the corner of the record amplifier card.)
3. Remove jumper J2 from the record amplifier card. (Removal of J2 eliminates any signal from the data channel VCO.)
4. Adjust R38 (bias current) for an oscilloscope signal of 500 mV_{p-p}. (R38 is the potentiometer closest to TP1.)
5. Install jumper J1 to position C-1. This position is used when the data input is not expected to exceed ±2.0 VDC. Position C-2 is used when the signal input is not expected to exceed ±10.6 VDC.
6. Install J2 to position C-1. This setting in conjunction with the SPEED switch position selects the proper center frequency for IRIG Wideband Group I.
7. Remove the bias oscillator circuit card from the recorder.
8. Apply a short circuit to the input at the input coaxial connector for the data channel.
9. Adjust R32 (carrier current) for an oscilloscope signal of 70 mV_{p-p}. (R32 is the second potentiometer from TP1.) Disconnect the oscilloscope from TP1 and TP2.
10. Connect the frequency counter between TP3 and TP1. (TP3 is located near the card extraction hole.)
11. Adjust R14 (center frequency) to 216.000 kHz. (R14 is the third potentiometer from TP1.)
12. Disconnect the input short circuit and apply +2.00 VDC to the data channel input.
13. Adjust R3 (deviation from center frequency) for 302.400 kHz. (R3 is the fourth potentiometer from TP1.)
14. Apply −2.00 VDC to the data channel input.
15. Frequency counter should read approximately 129.60 kHz.
16. Install jumper J1 to position C-2. Apply + and −10.6 VDC to the data channel input. Frequencies should approximate those for ±2.0 VDC.
17. Return J1 jumper to the position C-1. Reinstall the bias oscillator card in the recorder.
18. Remove all test equipment.

AD-A135 632 PARTICLE SIZING IN A FUEL-RICH RAMJET COMBUSTOR(U) JOHNS HOPKINS UNIV LAUREL MD APPLIED PHYSICS LAB R TURNER ET AL. AUG 83 JHU/APL/TG-1339 N00024-83-C-5301

2/2

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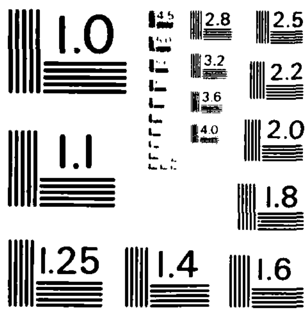
END
DATE FILMED
1-84
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS - 1963 - A

B. Reproduce Amplifier

1. Remove recorder power whenever a printed circuit card is removed or installed.
2. Verify that the 10 kHz filter (1677539-001) is installed at the "A" filter position on the card and that the record amplifier has been calibrated.
3. Set the recorder POWER and CALIBRATION switches to ON and allow at least five minutes for warm-up.
4. Set SPEED switch and "A" jumper pin (on control panel) to 15 ips.
5. Apply a short circuit to the input at the input coaxial connector for the data channel.
6. Connect a short jumper lead from TP3 on the record amplifier to TP2 on the reproduce amplifier. (Both test points are near the card extraction holes.)
7. Connect a DCVM or DC coupled oscilloscope to the output coaxial connector for the data channel.
8. Adjust R21 (the only potentiometer on the filter card) for zero volts.
9. Remove the short circuit at the data channel input and apply +2.00 VDC at the input.
10. Adjust R26 (the potentiometer at the corner of the reproduce amplifier) to produce 1.41 *VDC at the data channel output connector.*
11. Remove the interboard jumper and all test equipment.

C. Tape Recorder Sensitivity

1. Two levels of sensitivity are provided by installing jumper J1 on the record amplifier to either of two positions. For signals not expected to exceed a peak level equivalent to 2.0 VDC the jumper should be in position C-1. For signals as great as 10.6 VDC the jumper should be in position C-2. Position this jumper in each channel according to the anticipated amplitude of the input signal.

D. Honeywell Model 1858 CRT Visicorder with Model 1883-MPD Differential Amplifiers

1. Remove power from the unit before removing or replacing any modules.
2. Ensure that the capacitors C3 and C4 have been removed from *all* of the Model 1883 amplifiers. These capacitors are located beneath the metal shield on the printed circuit card. They serve as high frequency filters and their removal is necessary to acquire the widest possible bandwidth.
3. Verify that the J1 jumpers on the printed circuit cards of the amplifiers are positioned for BNC input, normal polarity. There should be a jumper from pin 3 to pin 7 and another from pin 4 to pin 5.
4. Apply power to the Visicorder and allow at least five minutes for warm-up.
5. Each of the Model 1883 differential amplifiers is to be calibrated as described in steps 6 through 13. The sensitivity switch on the front panel indicates calibrated (with TRIM control) deflection per major chart division (5 small divisions of 0.2 in. each) provided that the variable (VAR-CAL) control is set fully clockwise. The VAR-CAL control allows the sensitivity to be set to values that are less than the calibrated steps.
6. Open the paper access door on the Visicorder chassis and release the cradle latch to expose the face of the CRT. Turn the GRIDLINE switch to CONT, set the RECORD SPEED to 0.1 in/s. and depress the DRIVE button. There should be a series of bright spots 0.2 in. apart with every fifth one intensified.
7. On the front panel of the Model 1883 unit, set the controls as follows:
   a. SENS switch to 0.5 V per division.
   b. VAR-CAL control fully CW. This control and the TRIM control are 15-turn potentiometers; the POS control is a 22-turn potentiometer.
8. Apply a short circuit to the input coaxial connector.
9. Using the POS control, position the CRT spot associated with this amplifier over a gridline spot near the right side of the CRT.
10. Apply a 2.50 VDC signal to the input of the amplifier and adjust the TRIM control for a spot deflection of 5 major divisions (5 in.).
11. Repeat steps 8, 9, and 10 until there is no interaction between the controls.
12. For deflection sensitivities other than the calibrated positions of the SENS switch, apply a suitable DC signal to the input coaxial connector and adjust the VAR-CAL control for the desired sensitivity.
13. Apply a short circuit to the input coaxial connector and adjust the POS potentiometer for the desired trace position.

III. Signal Processing Instrumentation

Calibration is accomplished by using a simulated photomultiplier signal supplied by a gated pulse gen-

erator. The simulated signal generator can be adjusted to vary pulse width, amplitude, fringe frequency, and number of modulating fringes. By processing a suitable range of signals, recording the processed signals, and playing them back into the Visicorder, the system output will be known in terms of the input signal and a complete system calibration will result. Unless otherwise directed, oscilloscope inputs are to be high impedance, DC coupled.

A. Instrumentation Switch and Control Positions

1. Hewlett-Packard, Model 461A amplifier
   a. GAIN (DB): 20
2. LRS (LeCroy Research Systems) Model 161 Dual Discriminator (upper unit)
   a. TERMINATE: ↓
   b. NORMAL – DC PASS: ↑ (normal)
   c. OUTPUT WIDTH: 150
   d. OUTPUT WIDTH VERNIER: 10.00
3. LRS 161 Dual Discriminator (lower unit)
   a. TERMINATE: ↑
   b. NORMAL – DC PASS: ↓ (normal)
   c. OUTPUT WIDTH: 15
   d. OUTPUT WIDTH VERNIER: 4.900
4. Tennelec TC-214 Linear Amplifier and Single Channel Analyzer
   a. COARSE GAIN: 32
   b. FINE GAIN: 2.5
   c. ΔE, 0 to 1 V: 5.32
   d. E1, 0 to 10 V: 8.72
   e. DELAY: fully counter clockwise
   f. UNIPOLAR – BIPOLAR: ↓ bipolar
   g. DIR. – INV.: ↓ inverted
   h. L.E. – X.O.: ↑ leading edge
   i. ΔE – E: ↑ ΔE
   j. 10V – 1V: ↓ 1V
5. Ortec 457 Biased Time-to-Pulse Height Converter
   a. RANGE: 0.4μs
   b. MULTIPLIER: 1
   c. COARSE GAIN: 2
   d. FINE GAIN 0.5 - 1.5: 1.210
   e. OUTPUT DELAY: fully counterclockwise
   f. GATE: ↑ anticoincidence
   g. STROBE: ↑ internal
6. Mech-Tronics Model 504 Dual Linear Gates
   a. Verify that R12 has been changed from 2.2 kΩ to 18 kΩ.
   b. GATE WIDTH: fully clockwise
   c. GATE MODE: ↑NOR

B. Simulated Photomultiplier Signal

1. **IMPORTANT!** To avoid calibration errors take the following precautions to eliminate errors produced by signal loading, faulty measurements, and lack of signal symmetry.
   a. Loading the system input signal with a low impedance oscilloscope during calibration and disconnecting the oscilloscope during system operation will produce a large calibration error. The simulated photomultiplier signal should be routed through the *TSI photomultiplier terminator 10098* (50 Ω shunt toward the signal generator) to the 1 MΩ input of the monitoring oscilloscope and then continue on to the system input amplifier.
   b. Feedback from the system input amplifier tends to make the input signal amplitude difficult to measure with certainty. This problem may be avoided by either of the following procedures.

      PROCEDURE A: Remove the coaxial cable from the amplifier input and terminate the cable with a 50 Ω shunt. Set the signal amplitude to the required level, as measured on the oscilloscope, then remove the 50 Ω termination and reconnect the cable to the amplifier input.

      PROCEDURE B: Connect a 30 ft (or longer) coaxial cable between the oscilloscope and the amplifier input. This procedure will give a few clean measurable fringes of the input signal before the interference is fed back from the amplifier.
   c. Take care that both the negative-going and positive-going half cycles of the simulated signal are of equal width.
   d. Unless otherwise directed, maintain the amplitude of the signal at 20 mV.
2. Initial system adjustments will be made with a simulated photomultiplier signal consisting of 16 negative-going pulses occurring at a 50 MHz rate. Final adjustments will be made with 16 fringes over the range of 30 to 80 MHz. This range of signals with exactly 16 fringes is produced by varying the frequency and pulse width (to maintain equal negative- and positive-going portions) controls on the HP8007B pulse generator and the width of the gating pulse to the HP8007B. Signals are produced by following steps *a* through *d*.
   a. On the E-H Research Laboratories, Model 139B, set the controls to produce a positive-going pulse of approximately 4 V, 0.3 μs in duration, and occurring once every 0.5 ms. Apply this pulse to the gate input of the HP8007B and to the external trigger of the oscilloscope.

b. Adjust the pulse-period and pulse-width controls on the HP8007B until the leading edge of the negative-going pulses are exactly 20 μs apart and both the negative-going and the positive-going portions are 10μs wide at their midpoints. Adjust the pulse amplitude until the pulses are -20 mV with respect to ground.

c. Adjust the pulse-width control on the 139B until there are exactly 16 negative-going pulses.

d. The signal now appearing at the system input is the 50 MHz simulated photomultiplier signal that will be used for most of the calibration; this signal should be monitored with the oscilloscope.

C. LRS 161 Dual Discriminator (initial adjustment)

1. Apply the 16 fringe signal to the system input amplifier as described in III.B.1.a.
2. With a 50 Ω termination at the input of the oscilloscope amplifier, examine the output from one of the upper connectors of discriminator 1 (upper unit). There should be a single negative-going pulse of approximately 1.25 V amplitude and 400 ns duration.
3. Repeat step 2 for the output of discriminator 2 (lower unit). There should be exactly 16 negative-going pulses of approximately 1.25 V amplitude and 10 ns duration. Remove the 50 Ω termination.

D. Peak Sense and Hold

1. Observe the LOW PASS GATE output. Adjust WIDTH G for a positive-going pulse with 0.6 μs pulse width. Pulse amplitude should be approximately +5 V. This same pulse should appear at the BANDPASS GATE output.
2. Observe the LOW PASS RESET output. Adjust WIDTH R for a 20 μs wide pulse of about +5 V. This pulse should also appear at BANDPASS RESET output and at the GATE and RESET outputs of the TPHC channel.
3. Observe the NEGATIVE GATE output. It should be a negative-going 5 V pulse (from +5 to 0 V) of approximately 0.6 μs duration.

E. TC-214 Single Channel Analyzer (initial adjustment)

1. Observe the waveform of the MAIN AMP OUT connector. There should be a sinusoidal positive-going waveform followed by a negative-going excursion. Adjust the COARSE and FINE GAIN controls until the positive-going peak is exactly 9.0 V.
2. Attach a coaxial tee connector at the E1, ΔE OUT connector so that the waveform can be observed without interrupting the system interconnections. A positive 6 V, 0.5 μs pulse should appear about 2.5 μs after the sweep start. If no pulse appears adjust the E1, 0 TO 10 V control to a position that produces a pulse.
3. While observing the simulated signal input to the system, decrease the width setting on the 139B pulse generator until there are only 15 negative-going pulses. If no pulse appears at the E1, ΔE OUT connector, decrease the setting of the E1, 0 TO 10 V control until a pulse appears; then slowly turn the control clockwise until the pulse just disappears.
4. Increase the 139B width control to produce an input signal of 17 negative-going pulses.
5. Increase the setting of the ΔE, 0 TO 1 V control until a pulse appears at the E1, ΔE OUT connector; then slowly decrease the setting until the pulse just disappears.
6. Examine the E1, ΔE OUT resulting from input signals of 15, 16, and 17 negative pulses. There should be an output pulse only for the 16-fringe input.

F. TC-214 Single Channel Analyzer (final adjustment)

1. Final adjustment of the single channel analyzer (SCA) consists of setting the E1, 0 TO 10 V and ΔE, 0 TO 1 V controls so that an acceptance window is created for all 16 fringe signals in the 30 to 80 MHz range and that signals with more or less than 16 fringes are rejected. Because this decision is made on the peak amplitude of a waveform that is available at the MAIN AMP OUT connector, this signal will be measured as the input signal is varied over the operating range of the system; the peak amplitude measurements will then dictate the input conditions for final controls adjustments. This procedure is best illustrated by Table C-1.

   The chart shows that the greatest amplitude occurs for a 15-fringe signal (8.8 V) when the fringe frequency is 60 MHz. The lowest amplitude for a 17-fringe signal is 9.5 V at 30 MHz. It is clear that a window whose lower limit is slightly greater than 8.8 V and whose upper limit is slightly less than 9.5 V will accept all

Table C-1

Fringe Frequency (MHz)	*Peak Voltage at TC-214 MAIN AMP OUT*		
	15 fringes	*16 fringes*	*17 fringes*
30	8.5	9.0	9.5
40	8.7	9.2	9.7
50	8.5	9.0	9.5
60	8.8	9.4	9.8
70	8.6	9.2	9.6
80	8.8	9.2	9.8

signals having 16 fringes and reject all others. In this example, the lower limit signal (15 fringes, 60 MHz) is fed into the system and the E1, 0 TO 10 V control is first adjusted for a pulse at the E1, ΔE OUT connector. The control is then increased until the pulse just disappears. The upper limit signal (17 fringes, 30 MHz) is then introduced and the ΔE, 0 TO 1 V control is decreased until the pulse at E1, ΔE OUT just disappears. The adjustments are repeated and proper operation is verified by introducing 15, 16, and 17 fringes at the frequencies in the chart.

2. Prepare a chart such as the one in the example by introducing a simulated photomultiplier signal while observing all of the precautions given in III.B.1. The frequency of the fringes and their symmetry are controlled by the HP8007B and the number of fringes by the width of the gating pulse produced by the 139B.
   a. Carefully measure and record the positive peak amplitude at the E1, ΔE OUT connector for each signal condition. For your convenience the time per cycle for each frequency and the time for a 16-fringe signal (start of first fringe to start of 16th fringe) are listed in Table C-2 below.

Table C-2

Frequency (MHz)	*Time per cycle (ns)*	*Time for 16-fringe signal (ns)*
30	33.3	500
40	25.0	375
50	20.0	300
60	16.7	250
70	14.3	214
80	12.5	187

If your chart shows a voltage overlap between acceptable and unacceptable signals, it will be necessary to move slightly the setting of the OUTPUT WIDTH VERNIER on the lower unit (discriminator 2) of the LRS 161 and repeat the chart measurements.

3. Select the upper and lower window limits and make the final control adjustments as in the example of III.F.1.

G. Ortec Model 489 Delay Amplifier

1. Observe the output of the amplifier on a DC coupled oscilloscope. A 2 V negative-going signal will appear about 2.5 μs after the sweep start.
2. Adjust the DC ADJ until the baseline is at 0 V.

H. Ortec Model 457 Time to Pulse Height Converter (TPHC)

1. Apply a 20 mV signal of 16 fringes at 80 MHz to the system input amplifier.
2. Observe the POS OUTPUT with a DC coupled oscilloscope. The positive-going pulse that occurs approximately 4 μs after the input signal should be adjusted for a peak amplitude of 9.0 V with the COARSE GAIN and FINE GAIN controls.
3. Adjust the DC ADJ until the baseline is at 0 V.
4. Adjust the signal input for a 20 mV signal of 16 fringes at a fringe frequency of 30 MHz.
5. Adjust the BIAS LEVEL control for a peak positive signal of 1.0 V.
6. Repeat steps 1 through 5 until the output conditions are met without further adjustment of the TPHC controls.

I. Mech-Tronics 504 Linear Gate (low pass channel)

1. Apply to the system input a 16-fringe, 50 MHz, 20 mV signal.
2. With a DC coupled oscilloscope view the waveform at the SIG. OUT connector. It should be a rectangular pulse 18 to 20 μs in width and approximately 100 mV in amplitude.
3. Vary the input signal amplitude between the values of 20 and 40 mV. The pulse amplitude should rise and fall in step with the input variations.
4. Change the input signal to 15 fringes, then 17 fringes; there should be no signal output in either condition.

J. Mech-Tronics 504 Linear Gate (bandpass channel)

1. Repeat steps I.1-4.

K. Mech-Tronics 504 Linear Gate (TPHC channel)

1. Apply to the system input a 16-fringe, 50 MHz, 20 mV signal.
2. With a DC coupled oscilloscope, view the waveform at the SIG. OUT connector. It should be a rectangular pulse 18 to 20 μs wide and approximately 6 V in amplitude.
3. Change the input signal to 15 fringes, then 17 fringes; there should be no signal output in either condition.

IV. Complete System Calibration

The complete system calibration is accomplished by applying known signals to the system input amplifier, recording the processed signals on the Honeywell 5600 tape recorder, sending the reproduced signals to the Honeywell 1858 Visicorder, and relating the printed Visicorder output to the system input signal.

A. Preliminary Instructions and Precautions.

1. Ensure that the filter circuit (1 kΩ, 2000 pF) is properly connected between the linear gate outputs and the HP5600 recorder inputs.
2. Ensure that jumper J1 in the record amplifier of each record is in the correct position for the anticipated signal. See paragraph II.A.5. Signals that exceed the specified maximum (2 or 10.6 VDC) will produce an erratic output from the recorder making the Visicorder traces unintelligible.
3. It is especially important that the simulated photomultiplier signal precautions of Section III.B be strictly observed.
4. During the remainder of the calibration, the gating signal is removed from all three of the Model 504 Linear Gates, and their GATE MODE switches are placed in the BLOCK position. Upon completion of the calibration, the gating signal is restored and the GATE MODE switches returned to NOR.
5. Warm up all equipment at least 5 minutes before proceeding.

B. Low Pass and Bandpass Channels (tape record)

1. On the tape recorder, set the SPEED switch and "B" jumper pin in the 60 ips position.
2. Monitor the inputs of both data channels to the recorder.
3. Apply a 16-fringe 50 MHz signal to the system input amplifier and lower the signal amplitude until there is no change in the signal level to the recorder. This will occur when the input signal is at approximately 15 mV peak and this level becomes the lower limit of the calibration range. The upper limit is the level that produces a saturation in the system input amplifier; this level occurs slightly beyond 700 mV. Select signal levels at and between these extremes to provide a reasonable number of calibration points. Suggested values are 15 mV (or lower limit signal), 20, 30, 40, 50, 100, 150, 200, 250, 300, 400, 500, 600, and 700 mV.
4. For each value selected proceed as follows:
   a. Depress the D (drive) button to start the tape motion, and when the PL light near the POWER switch comes on, depress both the D and the REC buttons and note the reading on the tape footage indicator.
   b. When the tape footage indicator has increased by approximately 30 ft, note the indicator reading and depress the STOP button.

C. Low Pass and Bandpass Channels (tape playback and Visicorder chart record)

1. Position the traces of the Visicorder and adjust their sensitivities so that they are not apt to interfere with each other. Unused traces can be eliminated by placing the 1883 amplifier sensitivity switch in the OFF position.
2. Set the Visicorder chart speed at 4 ips.
3. On the tape recorder, set the SPEED switch and the "A" jumper pin to 15 ips. Position the tape so that the footage indicator reads a value lower than the beginning point for the calibration recording that is about to be fed to the Visicorder.
4. Depress the D button on the tape recorder and watch the footage indicator. When it approaches the midpoint of the recording range for that calibration point, depress and lock the DRIVE button on the Visicorder.
5. After 2 seconds of Visicorder operation, depress the DRIVE button to unlock it and press the STOP button on the tape recorder.
6. Repeat this procedure for each calibration point.

D. TPHC Channel (tape record)

1. On the tape recorder set the SPEED switch and "B" jumper pin to 60 ips.
2. Monitor the input to the recorder from the TPHC data channel.
3. Apply a 16-fringe, 30 MHz, 20 mV signal to the system input. A signal of approximately 1 V should be present at the recorder input.
4. Record the signal as in IV.B.4.
5. Repeat this procedure with 16-fringe signals of 40, 50, 60, 70, and 80 MHz.

E. TPHC Channel (tape playback and Visicorder chart record)

1. Follow the procedure of IV.C. to produce a Visicorder chart record for the TPHC frequency related outputs.

The calibration is complete when the output amplitude of the Visicorder is plotted against the signal amplitude or frequency producing that output. Restoring the gate input to the Model 504 Linear Gates, placing their GATE MODE switches to the NOR position, and reconnecting the photomultiplier through its termination (TSI 10098) to the system input amplifier restores the system to its normal operating configuration.

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A laser Doppler velocimeter (LDV) has been used to measure the size, concentration, and velocity of individual particles having diameters ranging from 3 to greater than 100 μm and having velocities of 600 to 1400 m/s in the fuel-rich exhaust of a ramjet combustor. The visibility of the LDV output was used to measure particle diameters ranging from 3 to under 30 μm and the mean scattered amplitude was used to measure particles ranging from 20 to over 100 μm. The attenuation of one LDV beam provided information on the total amount of material present. Measurements were made along the flow field of a combustor operating at 35 psia, an inlet temperature of 650 to 850 K, and fuel equivalence ratios (ER) of 1.6 and 2.6. Typically, at a point one-half inch from the nozzle and for an ER of 2.6, the average particle velocity is 800 m/s, the average particle size is 50 μm, and the particle density is 250 particles per cubic centimeter. The large particles appear to be unburnt fuel.

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PARTICLE SIZING IN A FUEL-RICH RAMJET COMBUSTOR

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